IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

SIEMENS MEDICAL SOLUTIONS USA, INC.,	)))	
Plaintiff,	))	
v.	))	C.A. No. 07-190 (SLR)
SAINT-GOBAIN CERAMICS & PLASTICS, INC.,	)))	**REDACTED – PUBLIC VERSION**
Defendant.	)	

AFFIDAVIT OF CHARANJIT BRAHMA

MORRIS, NICHOLS, ARSHT & TUNNELL LLP
Jack B. Blumenfeld (#1014)
Maryellen Noreika (#3208)
1201 North Market Street
P.O. Box 1347
Wilmington, Delaware 19899-1347
(302) 658-9200
jblumenfeld@mnat.com
Attorneys for Plaintiff
Siemens Medical Solutions USA, Inc.

OF COUNSEL:

Gregg F. LoCascio
Charanjit Brahma
Sean M. McEldowney
KIRKLAND & ELLIS LLP
655 Fifteenth St., N.W., Suite 1200
Washington, D.C. 20005
(202) 879-5000

Originally Filed: July 9, 2007
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IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

|		
SIEMENS MEDICAL SOLUTIONS USA, INC.,	:	
	:	Civil Action No. 07-190 SLR
Plaintiff,	:	
	:	
v.	:	
	:	
SAINT-GOBAIN CERAMICS & PLASTICS, INC.,	:	
	:	
Defendant.	:	
	:	

AFFIDAVIT OF CHARANJIT BRAHMA

I, Charanjit Brahma, declare and state that the following facts are true to the best of my knowledge, information and belief. I am an attorney with the law firm of Kirkland & Ellis LLP, and one of the attorneys for Plaintiff Siemens Medical Solutions USA, Inc. in the above captioned action. I am an attorney duly admitted to practice *pro hac vice* in this court.

1.   Attached hereto as Exhibit 1 is a true and correct copy of U.S. Patent No. 4,958,080.

2.   Attached hereto as Exhibit 2 is a true and correct copy of "Saint-Gobain - Innovation," from the internet web site located at http://www.saint-gobain.com.br/versao2006/ingles /inovacao.aspx.

3.   Attached hereto as Exhibit 3 is a true and correct copy of U.S. Patent No. 6,818,896.

4.   Attached hereto as Exhibit 4 is a true and correct copy of U.S. Patent No. 6,624,420.

5.   Attached hereto as Exhibit 5 is a true and correct copy of the April 26, 2006 Order granting interdict.

6.   Attached hereto as Exhibit 6 is a true and correct copy of Siemens' license for all fields of use other than "oil well logging, logging-while-drilling or formation evaluation."

7.   Attached hereto as Exhibit 7 is a true and correct copy of Leon Jaroff, *A Winning Combination,* Time Magazine, Dec. 4, 2000.

8. Attached hereto as Exhibit 8 is a true and correct copy of Philips Gemini Raptor TF Brochure.

9. Attached hereto as Exhibit 9 is a true and correct copy of Philips' 501(k) submission to the FDA.

10. Attached hereto as Exhibit 10 is a true and correct copy of *Philips showcases clinical results of time-of-flight imaging for PET/CT*, Health Imaging News, June 7, 2006, available at http://www.healthimaging.com/content/view/4470/89/.

11. Attached hereto as Exhibit 11 is a true and correct copy of *Philips' highlights enhanced PET/CT, 'green' BrightView SPECT*, Health Imaging News, June 6, 2007, available at http://www.healthimaging.com/content/view/6654/89/.

12. Attached hereto as Exhibit 12 is a true and correct copy of *Philips Medical Systems Gemini TF PET/CT system*, RT-Image, Mar. 27, 2007, available at http://www.rt-image.com/032706TS.

13. Attached hereto as Exhibit 13 is a true and correct copy of Saint-Gobain PreLude 420 Product Data Sheet dated June 2004.

14. Attached hereto as Exhibit 14 is a true and correct copy of Saint-Gobain LYSO Material Safety Data Sheet dated March 2007.

15. Attached hereto as Exhibit 15 is a true and correct copy the article "Society Awards" at http://www.ieee.org/organizations/pubs/newsletters/npss/0307/society.html.

· FURTHER AFFIANT SAYETH NOT.

Dated this _9th_ day of July, 2007

_____
Charanjit Brahma

District of Columbia)
)ss.
)

SUBSCRIBED AND SWORN to and before me this _9th_ day of July, 2007.

Kenya L. Davis
Notary Public, District of Columbia
My Commission Expires 4/14/2012

_____
Notary Public

CERTIFICATE OF SERVICE

I, the undersigned, hereby certify that on July 9, 2007, I electronically filed the foregoing with the Clerk of the Court using CM/ECF, which will send notification of such filing(s) to the following:

> Jesse A. Finkelstein, Esquire
> Jeffrey L. Moyer, Esquire
> Kelly E. Farnan, Esquire
> Richards, Layton & Finger, P.A.

I also certify that copies were caused to be served on July 9, 2007 upon the following in the manner indicated:

BY EMAIL & HAND

> Jesse A. Finkelstein, Esquire
> Jeffrey L. Moyer, Esquire
> Kelly E. Farnan, Esquire
> Richards, Layton & Finger, P.A.
> One Rodney Square
> Wilmington, DE 19801

BY EMAIL

> Frederick L. Whitmer, Esquire
> Thelen Reid Brown Raysman & Steiner LLP
> 875 Third Avenue
> New York, NY 10022

/s/ Jack B. Blumenfeld

Jack B. Blumenfeld (#1014)

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> Richards, Layton & Finger, P.A.
> One Rodney Square
> Wilmington, DE 19801

BY ELECTRONIC MAIL

> Frederick L. Whitmer, Esquire
> Thelen Reid Brown Raysman & Steiner LLP
> 875 Third Avenue
> New York, NY 10022

/s/ Maryellen Noreika

Maryellen Noreika (#3208)

EXHIBIT 1

United States Patent [19]

Melcher

[11]   **Patent Number:**   **4,958,080**

[45]   **Date of Patent:**   **Sep. 18, 1990**

[54]   **LUTETIUM ORTHOSILICATE SINGLE CRYSTAL SCINTILLATOR DETECTOR**

[75]   Inventor: **Charles L. Melcher,** West Redding, Conn.

[73]   Assignee: **Schlumberger Technology Corporation,** New York, N.Y.

[21]   Appl. No.:   **389,502**

[22]   Filed: **Aug. 4, 1989**

Related U.S. Application Data

[63]   Continuation of Ser. No. 254,353, Oct. 6, 1988, abandoned.

[51]   Int. Cl.^{5} **C09K 11/79; G01J 1/58**

[52]   U.S. Cl. .... **250/483.1;** 250/361 R; 252/301.4 F

[58]   Field of Search .... 252/301.4 F; 250/483.1, 250/361 R

[56]   **References Cited**

U.S. PATENT DOCUMENTS

4,208,611	6/1980	Watanabe et al.	.... 252/301.4 F
4,647,781	3/1987	Takagi et al.	.... 252/301.4 F

FOREIGN PATENT DOCUMENTS

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"Serie Isomorphe d'Orthosilicates (T_2SiO_5) et d'Orthogermanates (T_2GeO_5) De Terres Rares", Buisson et al., Mat. Res. Bull. vol. 3, pp. 193–198, 1968.

"Preparation and Cathodoluminescence of Ce^{3+}–Activated Yttrium Silicates and Some Isostructural Compounds", A. H. Gomes de Mesquita et al., Mat. Res. Bull. vol. 4, pp. 643–650, 1969.

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"Czochralski Growth of Rare–Earth Orthosilicates (Ln_2SiO_5)", Brandle et al., Journal of Crystal Growth 79 (1986) pp. 308–315.

"Sol-Gel Deposition of Tb^{3+}:Y_2SiO_5 Cathodoluminescent Layers", Rabinovich et al., Am. Ceram. Soc. Bull. 66[10] 1505–09 (1987).

"Characteristic Luminescence", Blasse et al., Philips Technical Review, vol. 31, 1970, No. 10.

"Development of New Scintillation Crystal Gd_2SiO_5: Ce for Gamma–Ray Detection", Ishii et al., submitted to 4th Experts Meeting on Positron CT between AIST Japan and STU Sweden, Stockholm, Mar. 17–20, 1986.

Primary Examiner—Jack Cooper
Attorney, Agent, or Firm—Brumbaugh Graves Donohue & Raymond

[57]   **ABSTRACT**

A scintillator for use as a gamma ray or like radiation detector is composed of a single crystal of cerium-activated lutetium oxyorthosilicate having the general formulation $Ce_{2x}Lu_{2(1-x)}SiO_5$. In a borehole logging application, the detector is mounted in a logging sonde with a high energy neutron source, for movement through a borehole traversing earth formations. Gamma radiation from the surrounding formations is detected and analyzed to provide information concerning hydrocarbons in the formations.

2 Claims, 2 Drawing Sheets

**U.S. Patent**   Sep. 18, 1990   Sheet 1 of 2   **4,958,080**


to amplifier ← ↘ to high voltage

FIG. 1
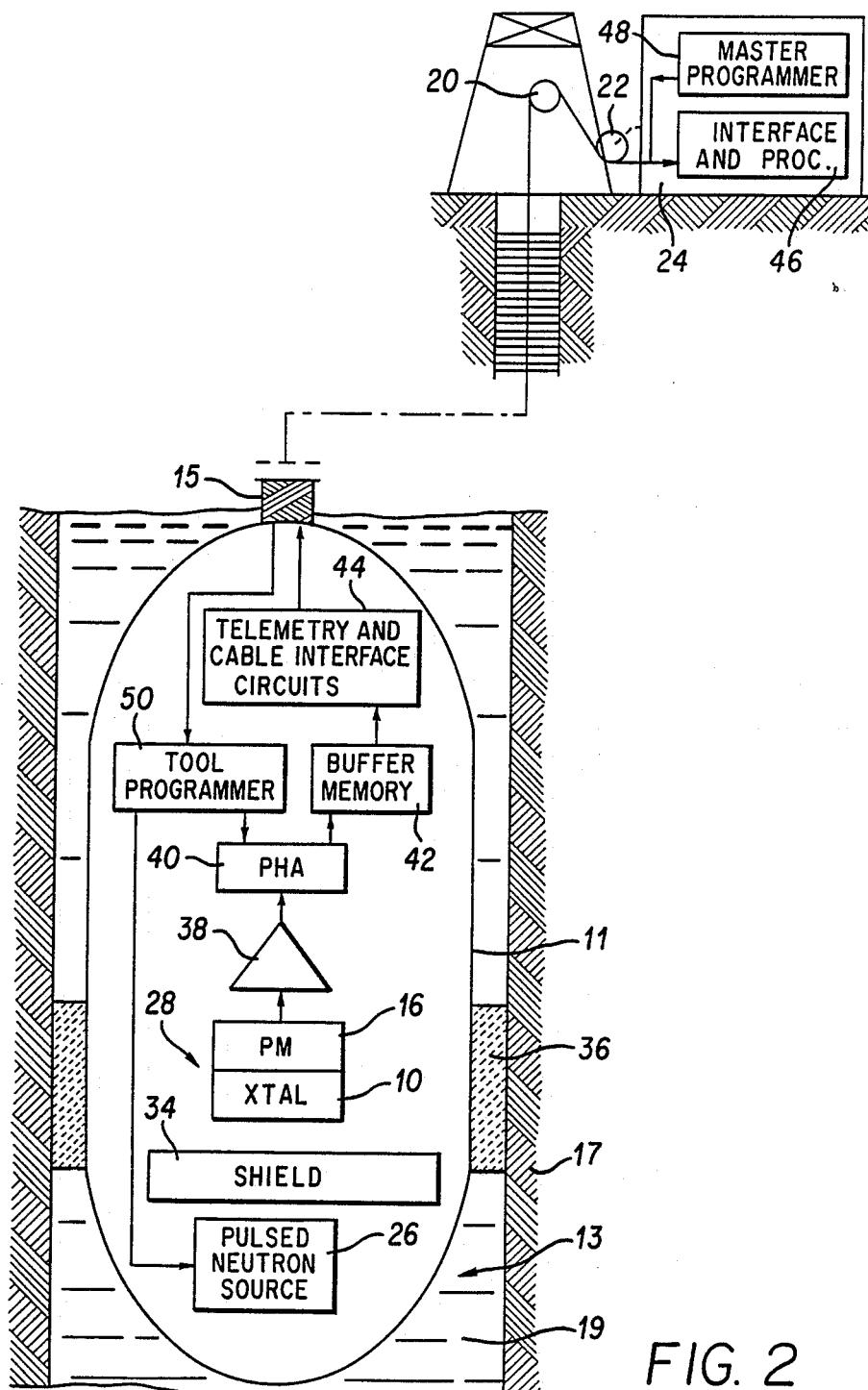
FIG. 2

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LUTETIUM ORTHOSILICATE SINGLE CRYSTAL SCINTILLATOR DETECTOR

BACKGROUND OF THE INVENTION

This application is a continuation, now abandoned of application Ser. No. 254,353, filed Oct. 6, 1988.

The present invention relates to a single crystal scintillation detector for gamma rays and like radiation and, more particularly, to a single crystal scintillation detector composed of lutetium orthosilicate.

A well-known form of detector for gamma rays and like radiation (such as x-rays, cosmic rays, and energetic particles of approximately 1 KeV and above) employs a transparent single crystal, known as a scintillator, which responds to impinging radiation to emit light pulses. The light pulses are optically coupled to the input of a photomultiplier tube, which generates a voltage signal related to the number and amplitude of the light pulses received. Scintillators of this class have found wide application in various fields, such as nuclear medicine, physics, chemistry, mineral and petroleum exploration, etc.

Perhaps the most widely used type of scintillator is thallium-doped sodium iodide, NaI (Tl). Relatively inexpensive to produce and capable of providing a high light output in response to impinging radiation, NaI detectors have found general use, for example, in logging tools for oil well logging operations, where either naturally occurring or induced gamma radiation is detected to aid in the location of petroleum deposits.

Other known single crystal scintillators used for gamma ray detection include cesium iodide (sodium or thallium activated) and bismuth germanate (BGO). Organic scintillators, such as naphthalene, anthracene, stilbene and similar materials, have also been employed, particularly where very high count rates are important, although they generally are not as useful as inorganic scintillators for the detection of gamma rays.

All of the foregoing types of scintillators have one or more disadvantages as gamma ray detectors. For example, NaI scintillators have comparatively low density, and thus low radiation detection efficiency, slow scintillation decay and a large and persistent afterglow, which impair counting rate performance and lead to pulse pile-up, and are hygroscopic. Although BGO scintillators do not suffer from the low density and hygroscopicity problems of NaI scintillators, they do have a relatively slow scintillation decay time and low light output, which drops still lower at higher temperatures. The index of refraction of BGO is also relatively high, resulting in light loss by internal reflection. These and other disadvantages of known scintillators have limited their usefulness as gamma ray detectors or have imposed restrictions on the manner of their use. In the harsh conditions (high temperature, high pressure, moisture, etc.) of oil well logging, for example, restrictions in logging speed, statistical reliability, tool size and the like have resulted directly from the scintillator material employed in a given logging tool. Accordingly, efforts have long continued to develop still more useful and reliable scintillation detectors and gamma ray scintillation detectors in particular.

More recently, a gamma ray detector employing a scintillator formed of a single crystal of cerium-activated gadolinium orthosilicate (GSO) has been proposed. The GSO scintillator has the advantages as a . gamma ray detector of high effective atomic number,

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high density, fast scintillation decay, relatively low index of refraction, but has the disadvantages of low light output, a strong tendency to cleave which makes cutting and polishing difficult, and, more significantly, very high thermal neutron capture cross section (49,000 barns). This last characteristic strongly suggested that GSO scintillators would have very limited utility, if any, in those applications, such as many nuclear well logging tools for instance, where the gamma radiation to be detected is induced by neutron irradiation. This is because gadolinium, upon the capture of thermal neutrons, emits gamma radiation which would interfere with the detection of the external gamma rays of interest.

Such a GSO scintillator detector is described in U.S. Pat. No. 4,647,781, issued Mar. 3, 1987, for use in positron computed tomography. There is no disclosure in the '781 patent, however, of the suitability of the GSO scintillator as a gamma ray detector in the hostile conditions of borehole logging. Indeed, it was the present inventor and his co-workers who, through experimentation and evaluation, first discerned that the GSO scintillator was useful as a borehole detector. This invention is disclosed in the copending, commonly-owned U.S. application Ser. No. 149,953 filed Feb. 2, 1988 by Charles L. Melcher et al., which is a continuation of U.S. application Ser. No. 812,220 filed Dec. 23, 1985. U.S. application Ser. No. 149,953 issued as U.S. Pat. No. 4,883,956, granted Nov. 28, 1989

Success in adapting the GSO scintillator to borehole use led the inventor to consider other rare earth compounds as possible scintillators for gamma ray (and the like) detection. As a first step, various phosphor materials were studied in powder form for initial evaluation in order to identify potential candidates for crystal growth. This initial evaluation was done using procedures similar to those described by A. H. Gomes de Mesquita et al. at pages 643–650 of Materials Research Bulletin, Vol. 4, No. 9, 1969, Pergamon Press, Inc., who were investigating the properties of rare-earth phosphors as their primary goal. The term phosphor as used in the Gomes de Mesquita et al. paper and as used herein refers to the fine powdered form. Such phosphors are typically used as coatings on cathode ray tube screens, fluorescent light bulbs, and the like, where they convert impinging electrons or ultraviolet radiation into visible light pulses. They are, however, not suitable as gamma ray or like radiation detectors since energetic photons or particles have high probability of passing through the thin coating with no interaction. If the coating is made sufficiently thick to stop gamma rays, the resulting opacity of the phosphor layer would trap most of the scintillation signal. Consequently, only transparent single crystals are useful as gamma ray detectors.

Although some of the physical and optical properties of the rare earth phosphors were known, their scintillation properties were not known and could not be predicted in advance because of the complex and only partially understood nature of the scintillation mechanism. For example, on the basis of atomic number, ionic radius, electronic charge, density, refractive index, and absence of absorption bands, cerium-doped ytterbium orthosilicate powder and cerium-doped lutetium orthosilicate powder would be expected to have very similar scintillation properties. In fact, however, the phosphor experiments showed that ytterbium orthosilicate has 1000 times less scintillation output compared to lutetium orthosilicate.

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Moreover, it was not at all clear whether the luminescence properties or other properties of the single crystal form of a rare earth compound would be the same as those of the phosphor form. Generally, in fact, the scintillation properties of single crystal scintillators are not readily determinable or predictable with certainty in advance from the phosphors.

SUMMARY

In accordance with the present invention, therefore, an improved scintillator for use as a gamma ray (or like radiation) detector is provided which comprises a single crystal of cerium-activated lutetium oxyorthosilicate having the general formulation $Ce_{2x}Lu_{2(1-x)}SiO_5$. Generally, the value of x (as measured in the initial melt from which the crystal is pulled) may be varied within the approximate range of from 0.001 to 0.1, with the preferred range of x being from approximately 0.005 to 0.015. When assembled in a complete detector, the scintillator crystal is optically coupled, either directly or through a suitable light path, to the photosensitive surface of a photodetector for generation of an electrical signal in response to the emission of a light pulse by the scintillator. The LSO scintillator of the invention possesses certain important characteristics, most notably high light output, very short decay time and high detection efficiency, that make it superior to prior scintillators as a gamma ray or like radiation detector, particularly in the borehole logging environment.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a diagrammatic view of one embodiment of an LSO scintillation detector in accordance with the present invention; and

FIG. 2 is a schematic diagram of a borehole logging sonde in which the LSO scintillation detector of FIG. 1 may be used.

DESCRIPTION OF REPRESENTATIVE EMBODIMENT

For illustrative purposes, a representative embodiment of the invention is described hereinafter in the context of a gamma ray detector. It will be understood, of course, that the utility of the novel LSO single crystal scintillator of the invention is not limited to the detection of gamma radiation but that it has general application to the detection of other types of like radiation, e.g. X-rays, cosmic rays, and energetic particles.

In FIG. 1, a single crystal LSO scintillator **10** is shown encased within the housing **12** of a gamma ray detector. One face **14** of the scintillator is placed in optical contact with the photosensitive surface of a photomultiplier tube **16**. Alternatively, the light pulses could be coupled to the photomultiplier via light guides or fibers, lenses, mirrors, or the like. The photomultiplier can be replaced by any suitable photodetector such as a photodiode, microchannel plate, etc. In order to direct as much of each light flash to the photomultiplier as possible, the other faces **18** of the scintillator are preferably surrounded or covered with a reflective material, e.g. Teflon tape, magnesium oxide powder, aluminum foil, or titanium dioxide paint. Light pulses emitted by the LSO crystal upon the incidence of radiation are intercepted, either directly or upon reflection from the surfaces **18**, by the photomultiplier, which generates electrical pulses or signals in response to the light pulses. These electrical output pulses are typically first amplified and then subsequently processed as de-

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sired, e.g. in a pulse height amplifier, to obtain the parameters of interest regarding the detected radiation. The photomultiplier is also connected to a high voltage power supply, as indicated in FIG. 1. Other than the LSO scintillator, all of the components and materials referred to in connection with FIG. 1 are conventional, and thus need not be described in detail.

As the first step in the evaluation of cerium-activated lutetium oxyorthosilicate $Ce:Lu_2SiO_5$ as a scintillator, the material was synthesized in phosphor (powder) form and the scintillation properties of the resulting compound were analyzed. From this analysis, it was determined that LSO was sufficiently promising as a scintillator material to warrant the additional effort and expense of growing in single crystal form. LSO was chosen as a candidate for phosphor synthesis because of its high atomic number and high density and the absence of optical absorption bands in the visible part of the spectrum. The principal physical and optical properties of LSO are compared to those of GSO and NaI (Tl) in Table 1, from which it may be seen that LSO appears to offer advantages over GSO in all properties and over NaI (Tl) in the areas of atomic number, density, index of refraction and hygroscopicity.

TABLE 1

	NaI(Tl)	GSO	LSO
Effective atomic number	51	59	66
Density (gm/cm³)	3.67	6.71	7.4
Index of Refraction	1.85	1.91	1.82
Neutron cross section (barns)	6.2	49,000	84
Hygroscopic?	yes	no	no

As Ce-activated single crystals of LSO had not previously been grown, the scintillation properties of single-crystal LSO were unknown. Also unknown, therefore, was whether the properties of the LSO phosphor would be retained when the same material was grown into a single crystal.

The phosphor synthesis procedure consisted of the following steps:

(1) Fine powders of Ln_2O_3 (Ln=Gd, Lu) SiO_2 and either CeO_2 or Ce_2O_3 in the appropriate atomic ratios were mechanically mixed and loaded into an alumina boat. In each case the molar concentration of Ce was 0.5% relative to Gd or Lu.

(2) Each of the four compositions was sintered at 1500° C. for four hours in a tube oven in one of three atmospheres: neutral (pure argon), reducing (argon +2% hydrogen), or oxidizing (air). When a reducing atmosphere was used, a high purity alumina furnace tube was employed because the standard mullite tube was found to react with hydrogen at high temperature and contaminate the samples. The resulting material was solid and was ground into a powder for analysis.

(3) The fluorescence emission of the powder was excited with ultraviolet light and the emission and excitation spectra were recorded with a Spex Fluorolog (Model 212) spectrofluorometer. For emission measurements above room temperature, the sample chamber was continuously flushed with argon to suppress spurious fluorescence emission which occurred when the sample was heated above 100° C. in air.

Table 2 shows the intensity of the fluorescence emission measured at room temperature.

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TABLE 2

	GSO:CeO$_2$	GSO:Ce$_2$O$_3$	LSO:CeO$_2$	LSO:Ce$_2$O$_3$
Argon + H$_2$	44	17	71	27
air	1.8	1.6	11	28
Argon	12	8.5	100	86

(4) The fluorescence decay times of the phosphors were measured by spreading a thin layer of the phosphor on the face of a fast photomuliplier (Amperex 2020Q) and exciting the emission with an [241]Am gamma-ray source. The pulse shape was observed at the anode of the photomultiplier with a fast oscilloscope and the decay time estimated from the oscilloscope trace.

Although the synthesis conditions employed were not necessarily optimum for each phosphor, inasmuch as the emission intensity of LSO was greater than that of GSO under all six synthesis conditions (three different atmospheres and two forms of cerium), it may be concluded that LSO's scintillation efficiency is intrinsically greater. The scintillation mechanism in cerium-activated phosphors is generally assumed to involve electronic transitions (5d to 4f) within the Ce^{+3} ion. For this reason, it was expected that the most efficient phosphors would result from using Ce$_2$O$_3$ (i.e., Ce^{+3}) as a starting material and performing the synthesis in a slightly reducing atmosphere (Ar+H$_2$) in order to maintain the cerium in the +3 charge state. Surprisingly, as Table 2 shows, in every case except LSO prepared in air the best phosphors were those in which Ce was added as CeO$_2$. Also note that although the best GSO phosphors were those prepared in a reducing atmosphere, the best LSO phosphors were those prepared in a neutral atmosphere. Synthesis in air resulted in phosphors with lower light output and, more importantly, with emission spectra that differed from the single crystal emission spectrum.

Table 3 summarizes the scintillation properties of GSO and LSO phosphors, synthesized in the foregoing manner:

TABLE 3

	GSO:CeO$_2$	LSO:CeO$_2$
Light output	1	1.5–10
Decay time	60 ns	50 ns
Emission peak	430 nm	415 nm
Temperature response	−0.4%/°C.	−1.3%/°C.

A comparison of the physical properties (Table 2) and the scintillation properties (Table 3) of GSO and LSO show LSO to be superior to GSO in most areas. The light output of LSO is a factor of 1.5 to 10 greater than GSO depending on the synthesis conditions. This is a particularly notable advantage over GSO. A comparison of the emission spectra of the GSO:CeO$_2$ and LSO:CeO$_2$ phosphors synthesized in argon (with the excitation light wavelength corresponding to the strongest excitation band for each phosphor, 345 nm for GSO and 355 nm for LSO) shows the LSO emission to

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have a different shape and to be shifted somewhat towards the shorter wavelengths than the GSO emission. This apparent shift of the LSO spectrum, if exhibited in the single crystal form, would be advantageous since it would result in an emission that better matches the spectral response of high temperature photomultipliers.

The scintillation decay time of LSO of about 50 ns compares favorably with GSO's 60 ns. The effective atomic number of LSO is 66 compared to 59 for GSO and the density of LSO is 7.4 gm/cc compared to 6.7 gm/cc for GSO, both of which contribute to a higher radiation detection efficiency for LSO. The index of refraction of LSO is 1.82 compared to 1.91 for GSO, which results in less trapping of scintillation light. LSO is very much less sensitive to neutrons, since the thermal cross section for Lu is 77 barns compared to 49,000 barns for Gd.

The temperature response of LSO is somewhat worse than GSO. At 150° C., GSO's light output decreases to about 60% of its room temperature value, while LSO's light output decreases to about 20% of its room temperature value at 150° C. On the other hand, the emission spectrum of LSO was found to shift somewhat to shorter wavelengths than the GSO emission as temperature increased from room temperature up to 175° C. (the highest temperature measured). Again this would be advantageous in the single crystal form in terms of matching photomultiplier response.

Lutetium has a radioactive isotope ([176]Lu) that produces a background noise level in the crystal. This could be eliminated by growing the crystal from pure [175]Lu, or it could be handled by conventional background subtraction techniques.

The excitation spectrum of LSO exhibits three bands (262 nm, 298 nm, and 355 nm) and is similar to the GSO excitation spectrum except that the bands are shifted to somewhat longer wavelengths.

Although the comparison of the LSO and GSO phosphors showed LSO to be a promising scintillator for use in a gamma ray detector, the properties of the single crystal form cannot be predicted with certainty. Light output, one of the most important properties of a single crystal scintillator, is especially difficult to predict from the phosphor form. In order to continue with a more detailed evaluation of the material as well as to test a practical detector, therefore, it was necessary to grow a single crystal form of LSO. This was done from melts by the conventional Czochralski method, as described, for example, by C. D. Brandle et al., "Czochralski Growth of Rare-Earth Orthosilicates (Ln$_2$SiO$_5$)", *Journal of Crystal Growth*, No. 79, pp. 308–315, 1986.

Table 4 summarizes the scintillation properties of the LSO single crystals grown, as selected and cut to minimize imperfections. The composition of the melts was Ce$_{2x}$Lu$_{2(1-x)}$SiO$_5$, where x is the decimal value of the percentage set out in Table 4 under the heading "Ce nom". Cerium concentration in the crystals was on the order of 20%–30% of that in the melt.

TABLE 4

	size (mm)	color	defects	Ce nom. (%)	light output (arbitrary unit)	energy res %	decay constant (ns)	emission max (UV excitation (nm)	emission max (gamma excitation (nm)
1	5 × 6 × 1	none	none	1.0	156	8.8	44	395	428
2	7 × 9 × 1	none	few	1.3	109	12	41	395	430
3	5 × 5 × 25	none	none	0.7	146	11.2	44	394	428

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TABLE 4-continued

size (mm)	color	defects	Ce nom. (%)	light output (arbitrary unit)	energy res %	decay constant (ns)	emission max (UV excitation (nm)	emission max (gamma excitation (nm)
4 5 × 5 × 1	none	few	0.6	104	13	38	393	426

Crystals **1, 2** and **4** were cut to the sizes listed from larger single crystals (5 mm × 6 mm × 28 mm, 7 mm × 9 mm × 27 mm and 8 mm × 8 mm × 33 mm, respectively), but crystal **3** was the original size. All were clear of

within the approximate range of from 0.1% to 10%, i.e., $0.001 \leqq X \leqq 0.1$. The preferred melt cerium concentration is within the range of from approximately 0.5% to 1.5%, i.e. $0.005 \leqq X \leqq 0.015$.

TABLE 5

	NaI(Tl)	BGO	GSO	LSO	
Relative light output (20° C.)	100	12	20	75	- signal-to-noise
Energy resolution (best)	6%	9%	8%	9%	
Decay time (ns)	230	300	60	41	- counting rate
Effective atomic no.	51	75	59	66	- detection eff.
Density (gm/cm³)	3.67	7.13	6.71	7.4	
Index of refraction	1.85	2.15	1.91	1.82	
Hygroscopic?	yes	no	no	no	- packaging
Mechanically rugged?	no	yes	no	yes	
Emission peak (nm at 20° C.)	410	480	430	428	
neutron cross section (barns)	6.2	2.2	49,000	84	
radiation length (cm)	2.6	1.1	1.4	1.1	

color and of high transparency, but crystals **2** and **4** had some defects. The light output was measured by coupling each crystal with optical coupling grease directly to a Hamamatsu R878 photomultiplier, with all surfaces except that coupled to the photomultiplier covered with Teflon tape (crystal **3**) or titanium dioxide paint (crystals **1, 2** and **4**). The scale employed for the light output measurements is expressed in arbitrary units. By comparison, on this scale the light output of a standard NaI (Tl) scintillator would be on the order of 200, and that for a standard GSO scintillator would be on the order of 40. The energy resolution was determined by using a standard cesium **137** gamma ray source. The energy resolution is expressed as the full width at half-maximum of the 662 KeV gamma ray peak. The scintillation decay time was exponential and had an average value of about 42 ns among the four crystals, as measured by the time-correlated, single photon technique.

Unexpectedly, the emission spectrum under gamma excitation was found to be different from the emission spectrum under ultraviolet excitation. The gamma emission spectrum peaked at approximately 426 nm—430 nm and was similar to the GSO emission spectrum. Also, both the gamma and ultraviolet-excited emissions exhibited a thermoluminescent effect with a half-life of about 10 minutes. The temperature response of the LSO crystals was not as good as GSO. The gamma-excited emission fell off at approximately 1.3% per degree C. Thus at 150°, the peak output is 20% of that at room temperature, which is similar to the temperature response of BGO. Accordingly, in those applications where high temperatures are anticipated, such as in certain oil well logging tools, the LSO scintillator may need to be isolated from the environment by a Dewar flask or other insulator.

Based on the data of Table 4 and previous experience with other single crystal scintillators and powder phosphors, it is expected that satisfactory LSO single crystal scintillators can be produced with cerium concentrations (in the melt from which the crystal is pulled)

Table 5 compares the principal physical and scintillation properties of the LSO single crystals with those for NaI(Tl), BGO, and GSO. With the NaI(Tl) crystal arbitrarily assigned a reference light output value of 100, it may be seen that the LSO crystal at 75 is markedly superior to the BGO and GSO crystals and only 25% below the NaI(Tl) value. The energy resolution of the LSO scintillator compares quite favorably with BGO and GSO and, again, was only slightly worse than NaI(Tl). The signal-to-noise performance of the LSO scintillator, therefore, is much improved relative to the BGO and GSO detectors. Although somewhat lower than NaI(Tl) in signal-to-noise ratio, LSO possesses other properties that are superior to NaI(Tl).

Thus the average decay time of 41 ns is shorter than any of the other three crystals and is some 5 to 6 times shorter than NaI(Tl). The LSO scintillator, therefore, is particularly useful in high counting rate detectors. LSO also has a very high gamma ray detection efficiency by virtue of its high effective atomic number and density. It is superior in this respect to both NaI(Tl) and GSO and is comparable to BGO. High detection efficiency further contributes to LSO's suitability for high counting rate applications.

Other favorable properties of LSO apparent from Table 5 include its low index of refraction, which results in less internal light loss than any of the other four scintillators. LSO is also non-hygroscopic, a particular advantage for oil well logging applications or other wet environments. Its mechanical ruggedness is superior to both NaI(Tl) and GSO, a feature which is also desirable for well logging and other uses where rough handling is encountered.

As already noted, the gamma emission peak is at approximately 428 nm, which is substantially the same as GSO and only slightly above NaI(Tl). A good match to the typical photomultiplier spectral response results. The neutron cross section is especially favorable in comparison to GSO, 84 barns vs. 49,000 barns. Hence the occurrence of interfering gamma rays due to neu-

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tron capture within the crystal is greatly reduced relative to GSO. Finally, the radiation length of LSO is as good as that of BGO and considerably shorter than either GSO or NaI, with consequent advantages in the crystal size required.

As may be appreciated from Tables 4 and 5, the LSO single crystal scintillator is comparable to or exceeds other known scintillators in nearly all properties important for use as a gamma ray detector, i.e., light output, energy resolution, efficiency of detection of high energy photons, scintillation decay time, hygroscopicity, susceptibility of crystal to mechanical damage, refractive index, emission spectrum match to photo-multiplier tube response, transparency of the crystal to its own scintillation emission, and absence of induced gamma radiation within the crystal. The only area in which LSO compares unfavorably is in the temperature sensitivity of the gamma-excited emission. In controlled environments, e.g. laboratories, hospitals, etc., this presents no problem. Even in high temperature environments, moreover, the unique combination of light output, speed, and detection efficiency found in LSO will in many instances justify the additional effort of isolating the scintillator from environmental temperature changes.

As discussed above, the LSO scintillator detector of the present invention is particularly effective as a radiation detector in a borehole logging environment, such as for petroleum exploration. In such use, the detector forms part of a logging system which may be of the type disclosed in the aforementioned copending U.S. application Ser. No. 149,953 and illustrated in FIG. 2 herein.

FIG. 2 shows a logging sonde 11 for sensing gamma radiation resulting from bombardment of a formation with high energy neutrons and detecting the energy of the radiation for subsequent spectral analysis. The sonde 11 is suspended in a borehole 13 on an armored multiconductor cable 15. The borehole 13 traverses a formation 17 and is filled with fluid 19, and may be open as shown or cased. The sonde 11 as described below may be constructed in accordance with U.S. Pat. No. 4,317,993 to Hertzog, Jr. et al, assigned to the assignee of the present application. The sonde 11 is moved in the borehole 13 by playing the cable 15 out and reeling it back in over a sheave wheel 20 and a depth gauge 22 by means of a winch forming part of a surface equipment 24. Usually the logging measurements are actually made while the sonde 11 is being raised back up the borehole 13, although in certain circumstances they may be made on the way down instead or as well.

The sonde 11 includes a pulsed neutron source 26 for producing primary radiation to bombard the formation 17 with fast neutrons as the sonde 11 travels up the borehole 13, and a radiation detector 28 for detecting secondary (gamma) radiation induced thereby in the borehole 13 and the formation 17. The neutron source 26 is preferably of the pulsed accelerator type described in U.S. Pat. Nos. 3,461,291 to Goodman and 3,546,512 to Frentrop, both commonly owned with this application. This type of source is particularly suited to the generation of discrete bursts of high energy or fast neutrons, e.g. at 14 MeV, with a controlled duration and repetition rate.

The detector 28 is of a type appropriate to the detection of gamma radiation and the production of an electrical signal corresponding to each detected gamma ray and having an amplitude representative of the energy of the gamma ray. To this end the detector 28 is as shown in FIG. 1, including a cerium-activated LSO scintillation crystal 10 optically coupled to a photomultiplier tube (PMT) 16. Suitable tubes are manufactured by EMR Photoelectric, Princeton, N.J.

Although not as important as in the case of a GSO scintillator, a neutron shield 34 may be located between the source 26 and the detector 28 to limit direct bombardment of the detector 28 by neutrons from the source 26, thereby avoiding saturation of the detector 28 by such direct irradiation. In addition, especially in the case of measurement of capture gamma radiation, the sonde 11 may be surrounded by a sleeve 36 impregnated with boron carbide and located in the general vicinity of the source 26 and the detector 28. This sleeve displaces borehole fluid in the region of the detector 28, and absorbs neutrons scattered by the formation towards the detector 28, without significantly attenuating gamma radiation emanating from the formation. The net effect is to reduce the possiblity of neutron interactions with the borehole contents and the material of the sonde 11 in proximity to the detector 28 and which would otherwise produce detectable gamma rays constituting an undesirable perturbation of the required gamma ray measurement.

Electrical power for the sonde 11 is supplied via the cable 15 from the surface equipment 24. The sonde 11 includes power conditioning circuitry (not shown) for feeding power at appropriate voltage and current levels to the source 26, the detector 28 and other downhole circuits. These circuits include an amplifier 38 and associated circuitry which receives the output pulses from the PMT 16. The amplifed pulses are then applied to a pulse height analyzer (PHA) 40 including an analog-to-digital converter which may be of any conventional type such as the single ramp (Wilkinson rundown) type. Other suitable analog to digital converters may be used for the gamma ray energy range to be analyzed. Linear gating circuits may also be employed for control of the time portion of the detector signal frame to be analyzed. Improved performance can be obtained by the use of additional conventional techniques such as pulse pile-up rejection.

The pulse height analyzer 40 assigns each detector pulse to one of a number (typically in the range 256 to 8000) of predetermined channels according to its amplitude (i.e. the gamma ray energy), and produces a signal in suitable digital form representing the channel or amplitude of each analyzed pulse. Typically the pulse height analyzer 40 includes memory in which the occurrences of each channel number in the digital signal are accumulated to provide an energy spectrum. The accumulated totals are then transferred via a buffer memory 42 (which can be omitted in certain circumstances) to telemetry and cable interface circuits 44 for transmission over the cable 15 to the surface equipment 24.

At the surface the cable signals are received by cable interface and signal processing circutis 46. It will be understood that the circuits 44 and 46 may be of any suitable known construction for encoding and decoding, multiplexing and demultiplexing, amplifying and otherwise processing the signals for transmission to and reception by the surface equipment 24. Appropriate circuits are described, for example, in U.S. Pat. No. 4,012,712 to Nelligan.

The operation of the sonde 11 is controlled by signals sent downhole from a master programmer 48, located in te surface equipment 24. These signals are received by a

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tool programmer **50** which transmits control signals to the neutron source **26** and the pulse height analyzer **40**.

The surface equipment **24** includes various electronic circuits used to process the data received from the downhole equipment, analyze the energy spectrum of the detected gamma radiation, extract therefrom information about the formation **17** and any hydrocarbons that it may contain, and produce a tangible record or log of some or all of this data and information, for example on film, paper or tape. These circuits may comprise special purpose hardware or alternatively a general purpose computer appropriately programmed to perform the same tasks as such hardware. Details of such analysis form no part of this invention and will not be described here, but may be found for example in U.S. Pat. No. 3,521,064.

Although the invention has been described and illustrated by reference to representative embodiments thereof, it will be understood that such embodiments

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are susceptible of modification and variation without departing from the inventive concepts disclosed. All such modifications and variations, therefore, are intended to be included within the spirit and scope of the appended claims.

I claim:

1. A gamma ray or x-ray detector, comprising: a scintillator composed of a transparent single crystal of cerium-activated lutetium oxyorthosilicate having the general formulation $Ce_{2x}Lu_{2(1-x)}SiO_5$, where x is within the range of from approximately 2×10^{-4} to approximately 3×10^{-2}, and

a photodetector optically coupled to the scintillator for producing an electrical signal in response to the emission of a light pulse by the scintillator.

2. The detector of claim **1** wherein x is within the range of approximately 1×10^{-3} to approximately 4.5×10^{-3}.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,958,080

DATED : September 18,1990

INVENTOR(S) : Charles L. Melcher

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page, item [63], AND col. 1, line 6, after "continuation" insert -- in part --;

Col. 1, line 6, delete "now abandoned":

Col. 1, line 7, after "1988" insert -- , now abandoned --.

Signed and Sealed this

Ninth Day of June, 1992

Attest:

DOUGLAS B. COMER

Attesting Officer   *Acting Commissioner of Patents and Trademarks*

EXHIBIT 2

.: Saint-Gobain :.

SAINT-GOBAIN

General Delegation for Brazil and Argentina

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Innovation

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- Budget of 350 million Euros in 2004, with growth of 10% in 2005
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- 3,000 researchers of all nationalities
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- About 100 development centers in the various countries in which the Group is set up

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▲ **Windows with controlled opacity:** PRIVA-LITE© is a laminated glass with a crystal liquid film. By means of an electrical control, the glass can become opaque at the desired degree. Applied in windows, it can guarantee privacy, eliminating the use of curtains or Persian blinds.
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Electrochromic automobile glass: LIGHTUNING© laminated glass, which can be darkened at different levels by means of an electrical control, until it becomes completely dark, preventing entry of light. Ferrari was the first manufacturer to adopt a roof with this glass in its Superamerica model.
www.saint-gobain-vetrotex.com.br

➤ **Glass for photovoltaic cells:** ALBARINO© glass was specially developed by Saint-Gobain for use in photovoltaic cells. It is an extra clear glass, with low iron oxide content and has a surface texture that reduces radiation reflection and absorption by the glass.
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➤ **Brasiflex – fibrocement without asbestos:** fibrocement roof tiles have about 50% market share in roofs in Brazil, considering all roof materials. Brasilit, this market's leader with 25 % share, was a pioneer during its launching in 1940, and it is now, since the end of 2001, a pioneer again with the total replacement of asbestos in the product's manufacturing. **The only company in the sector to replace asbestos, currently using a cut polypropylene thread in its place.**
www.brasilit.com.br

➤ **New glass wool generation:** ULTIMATE is a new generation of glass wool developed by Saint-Gobain, which combines the qualities of glass wool and those of rock wool. It is light, compressible and resistant to high temperatures of up to 650 °C. Its main advantage is the insulation of constructions that need fire protection.
www.saint-gobain-isover.com.br

CENTER OF HIGH PERFORMANCE MATERIAL PRODUCTION

➤ **Particle filter for diesel engines:** filter is manufactured with extra pure recrystallized silicon carbide and eliminates 99.9 % of particles emitted by diesel engine combustion, protecting the environment

.: Saint-Gobain :.

and public health. It enables automobile manufacturers to meet strict European norm requirements pertaining to exhaust emission standards.

➤ **Sapphire Window:** Saint-Gobain produces the largest sapphire windows in the world: 30 cm wide and 50 cm long. Sapphire is the second hardest material (after diamond) and is chemically inert. It is a very pure, very hard and transparent monocrystal. The advantage of sapphire window is its resistance to extreme mechanical and chemical conditions.

These windows are used in civil and military aviation, especially to facilitate landing at night or in low-visibility situations. Other applications: sapphire windows are used to monitor manufacturing processes involving chemical products, such as the cleaning phase of chips and electronic circuits.

Small and thin sapphire plates are installed on the glass of bar code readers in supermarkets to prevent wear and wrong reading. They are also applied in medical equipments in laser systems.
www.saint-gobain-plasticos.com.br

➤ **Plastic solar panel reinforced with glass fiber:** the use of plastic reinforcement with TWINTEX□ fiberglass blankets, in replacement of metal, allowing the manufacture of smaller, lighter and more efficient solar panels.
www.saint-gobain-vetrotex.com.br

➤ **Resistant and elastic multi-layered film:** FLUOROLEASE© A is a multi-layered film that combines a very thin external layer of propylene fluoroethylene copolymer on an elastomeric base. This creates a material with high capacity to withstand heat, maintaining its´elasticity. It has applications in the aeronautics industry, in photovoltaic cells and in flexible printed circuit boards, among others.
www.saint-gobain-plasticos.com.br

➤ **Crystals for scanners:** PRELUDE 420 is a crystal developed by Saint-Gobain, whose main application is in tomographic devices to detect gamma ray emissions in medical exams for identifying tumors.
www.saint-gobain-ceramicas.com.br

➤ **Moldable vitroceramic:** MICAVER© HT is a moldable vitroceramic that withstands high temperature. It retains the moldability of plastic and heat resistance of ceramics. It has applications in igniters for gas heaters, sockets for halogen lamps and automobile engine parts.
www.saint-gobain-ceramicas.com.br

➤ **Anti-electrostatic ceramic:** CERASTAT© is a new ceramic that enables gradual dissipation of electrostatic loads, used to protect hard disks and microelectronic products during their manufacturing, testing and use.
www.saint-gobain-ceramicas.com.br

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EXHIBIT 3

US006818896B2

(12) **United States Patent**

Pauwels et al.

(10) **Patent No.:**   **US 6,818,896 B2**

(45) **Date of Patent:**   ***Nov. 16, 2004**

(54) **SCINTILLATOR CRYSTALS AND THEIR APPLICATIONS AND MANUFACTURING PROCESS**

(75) Inventors: **Damien Pauwels**, Evry (FR); **Bruno Viana**, Montgeron (FR); **Andree Kahn-Harari**, Paris (FR); **Pieter Dorenbos**, GM Rijswijk (NL); **Carel Wilhelm Eduard Van Eijk**, LS Delft (NL)

(73) Assignee: **Saint-Gobain Cristaux & Detecteurs**, Courbevoie (FR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 328 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **10/196,950**

(22) Filed: **Jul. 18, 2002**

(65) **Prior Publication Data**

US 2003/0062465 A1 Apr. 3, 2003

Related U.S. Application Data

(63) Continuation of application No. 09/686,972, filed on Oct. 12, 2000, now Pat. No. 6,437,336.
(60) Provisional application No. 60/225,400, filed on Aug. 15, 2000.

(51) **Int. Cl.**[7] **G01J 1/58**; C09K 11/79
(52) **U.S. Cl.** .... **250/361 R**; 250/483.1; 252/301.4 F
(58) **Field of Search** .... 250/361 R, 483.1; 252/301.4 F

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Primary Examiner—Scott J. Sugarman
Assistant Examiner—Richard Hanig
(74) *Attorney, Agent, or Firm*—Pennie & Edmonds LLP

(57)   **ABSTRACT**

A monoclinic single crystal with a lutetium pyrosilicate structure is described. The crystal is formed by crystallization from a congruent molten composition of $LU_{2(1-x)}M_{2x}Si_2O_7$ where LU is lutetium or a lutetium-based alloy which also includes one or more of scandium, ytterbium, indium, lanthanum, and gadolinium; where M is cerium or cerium partially substituted with one or more of the elements of the lanthanide family excluding lutetium; and where x is defined by the limiting level of LU substitution with M in a monoclinic crystal of the lutetium pyrosilicate structure. The LU alloy should contain greater than about 75 weight percent lutetium. The crystals exhibit excellent and reproducible scintillation response to gamma radiation.

51 Claims, No Drawings

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SCINTILLATOR CRYSTALS AND THEIR APPLICATIONS AND MANUFACTURING PROCESS

RELATED APPLICATIONS

This application is a continuation of pending application Ser. No. 09/686,972 filed Oct. 12, 2000, now U.S. Pat. No. 6,437,336, which claims priority from provisional application No. 60/225,400, filed Aug. 15, 2000.

FIELD OF THE INVENTION

The present invention relates to scintillator crystals, to a manufacturing process allowing them to be obtained and to the use of the said crystals, especially in gamma-ray and/or X-ray detectors.

BACKGROUND OF THE INVENTION

A scintillator crystal is a crystal which is transparent in the scintillation wavelength range which responds to incident radiation by emitting a light pulse. Scintillator crystals are widely used in detectors for gamma-ray, X-rays, cosmic rays and particles whose energy is of the order of 1 keV and greater. From such crystals it is possible to manufacture detectors in which the light emitted by the crystal that the detector comprises is coupled to a light-detection means and produces an electrical signal proportional to the number of light pulses received and to their intensity. In scintillation devices the detector is generally a single scintillator crystal.

Solid state scintillator crystals are in common use as components of radiation detectors in X-ray detection apparatus such as counters, image intensifiers and computerized tomography (CT) scanners. Such detectors are used especially in the fields of nuclear medicine, physics, chemistry and oil well logging. One embodiment of the present generation of scintillators comprises oxide mixtures in which a rare earth oxide is present as an activator, along with various combined matrix elements which are also usually rare earth oxides. Other combined metals may also be present as additives for specific purposes. These scintillators have been characterized by the advantageous properties of high efficiency, moderate decay time, low afterglow and little or no radiation damage upon exposure to high X-ray doses.

A family of known scintillator crystals widely used is of the thallium-doped sodium iodide, or NaI:T1, type. Crystals of the NaI:T1 family have a low density and therefore a low detection efficiency for certain types of high-energy radiation; they also have hygroscopic problems.

Another family of scintillator crystals is of the barium fluoride (BaF$_2$)type. Crystals of the BaF$_2$ family are not very dense and their rapid emission component lies within the ultraviolet range, which means the use of expensive photodetectors in scintillation devices.

Another family of scintillator crystals which has undergone considerable development is of the bismuth germanate (BGO) type. Crystals of the BGO family have a long scintillation decay time which limits the use of such crystals to low counting rates.

A more recent family of scintillator crystals was developed in the 1980s and is of the cerium-activated gadolinium orthosilicate (GSO) type. Crystals of the GSO family have a low optical yield and a strong tendency to cleave, which makes them extremely difficult to prepare.

A new family of crystals was developed at the end of the 1980s in order to obtain scintillator crystals having a high light yield, short luminescence decay times and a high

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detection efficiency: these crystals are of the cerium-activated lutetium oxyorthosilicate (LSO) type and formed the subject-matter of patent U.S. Pat. No. 4,958,080. A method of growing such a crystal formed the subject-matter of patent U.S. Pat. No. 5,660,627. Although the scintillation properties of the crystals of this family are excellent, they do have a major drawback with regard to reproducibility, which has a negative impact on the development of their use. This is because the results of scintillation properties between two crystals of the same composition may vary very considerably as indicated, for example, by the following publications: "Ce-doped scintillators: LSO and LuAP" (A. Lempicki and J. Glodo, Nuclear Instruments and Methods in Physics Research A416 (1998), 333–344) and "Scintillation Light Emission Studies of LSO Scintillators" (A. Saoudi et al., IEEE Transactions on Nuclear Science, Vol. 46, No. 6, December 1999). These authors indicated in particular the difficulties of using LSO owing to very large variations in the scintillation properties of LSO single crystals from one crystal to another, even when they are cut from the same ingot.

Another drawback with LSO relates to its high melting point, about 2200° C. and this means that the process allowing such a crystal to be obtained requires high temperatures.

The latest scintillator compositions employ at least one of the oxides of lutetium, yttrium and gadolinium as matrix materials. These are described in detail, for example, in U.S. Pat. Nos. 4,421,671, 4,473,513, 4,525,628, 4,783,596, and 6,093,347. These crystals typically comprise a major proportion of yttria (i.e., Y$_2$O$_3$), up to about 50 mole percent gadolinia (Gd$_2$O$_3$) and a minor activating proportion of a rare earth activator oxide. Suitable activator oxides, as described in the aforementioned patents, include the oxides of europium, neodymium, ytterbium, dysprosium, terbium and praseodymium. Europium-activated scintillators are often used in commercial X-ray detectors by reason of their high luminescent efficiency, and low afterglow level. Decay times of such scintillators are on the order of 0.9–1.0 millisecond.

The search thus continues for scintillator compositions having improved properties.

SUMMARY OF THE INVENTION

The object of the present invention is to alleviate these drawbacks and to propose a novel family of scintillator crystals whose scintillation properties are of the same order of magnitude as those of LSO crystals, wherein the property variations from one crystal to another of the same composition are very much less than the property variations from one LSO crystal to another of the same composition.

One crystal according to the invention is a monoclinic single crystal obtained by crystallization of a congruent molten composition of general formula:

$$LU_{2(1-x)}M_{2x}Si_2O_7$$

where LU is selected from lutetium, or a lutetium-based alloy which also includes one or more of the elements Sc, Y, In, La, Gd; where M is cerium, or cerium partially substituted with one or more of the elements of the lanthanide family (excluding lutetium); and where x is a variable defined by the limiting level of Lu substitution with M in a monoclinic crystal of the lutetium pyrosilicate (LPS) structure.

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DETAILED DESCRIPTION OF THE INVENTION

One crystal according to the invention is a monoclinic single crystal obtained by crystallization of a congruent molten composition of general formula:

$$LU_{2(1-x)}M_{2x}Si_2O_7$$

where LU is selected from lutetium, or a lutetium-based alloy which also includes one or more of the elements Sc, Y, In, La, Gd; where M is cerium, or cerium partially substituted with one or more of the elements of the lanthanide family (excluding lutetium); and where x is a variable defined by the limiting level of Lu substitution with M in a monoclinic crystal of the lutetium pyrosilicate (LPS) structure.

The invention allows of producing scintillator crystals of high quality based on lutetium alloys. Lutetium is a very expensive metal. It is possible by utilizing alloys to retain the host lattice structure for dopants that lutetium pyrosilicate offers, while considerably reducing the cost of the raw materials needed to produce the scintillator crystal. This solution is also advantageous as it makes it possible to lower the melting point of the crystal. The elements mentioned for making up the said alloy are optically inert. Typically, if a lutetium-based alloy is used, the quantity of Sc, Y, In, La, and Gd is less than about 25% by weight of the lutetium-based alloy.

It is also possible to obtain monoclinic single crystals according to the invention in which lutetium is mixed with one or more elements from Sc, Y, In, La, Gd, in order to form an alloy in which the LPS structure is retained and in which it is possible to insert cerium or cerium partially substituted with one or more of the elements from the lanthanide family other than lutetium (elements of atomic number ranging between 57 (in the case of lanthanum) and 70 (in the case of ytterbium)).

According to another variant, the crystal is of general formula:

$$LU_{2(1-x)}M_{2x}Si_2O_7$$

where x is defined by the limiting level of Lu substitution with M in a monoclinic crystal of the lutetium pyrosilicate (LPS) structure.

According to another variant, the crystal is of general formula:

$$LU_{2(1-x)}Ce_{2x}Si_2O_7$$
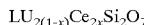
where x is defined by the limiting level of Lu substitution with Ce in a monoclinic crystal of the lutetium pyrosilicate (LPS) structure.

Advantageously, the level of x substitution is less than 0.5 at %, preferably less than 0.2 at % and more preferably less than 0.1 at %. In certain embodiments, the level of x substitution is greater than 0.0001 (or 0.01%) and in other embodiments the level of x is greater than 0.0005 (or 0.05%).

According to an advantageous variant, the single crystal according to the invention has at least two dimensions each greater than 3 mm, preferably greater than 5 mm, and even more preferably greater than 10 mm. The crystals of this size are advantageously obtained by growth from a congruent melt pool using the Czochralski method. The Czochralski method is known by those skilled in the art for growing single crystals.

An important embodiment of the invention is compositions wherein the single crystals produced from the same

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chemical composition have a relative variation in light yield under identical excitation of less than 50%. In a preferred embodiment of the invention, at least 80 percent of crystals with the same composition, prepared in the same method using the same reactants, will vary in photons/MeV response to a gamma source such as [241]Am by less than 20%.

Without being theory, it may be considered that the excellent scintillation results and the good reproducibility which are observed in LPS single crystals may be due to the presence of insertion sites of a single type in the lutetium pyrosilicate structure, whereas the heterogeneity problems in the LSO crystals are especially due to the possible presence of several insertion sites for the cerium in the LSO structure.

An important embodiment of the invention is compositions which melt at a temperature of less than 2200° C., preferably less than 2100° C., even more preferably less than 2000° C., for example around 1900° C.

In another embodiment of the invention the decay time for the crystal is less than about 70 nanoseconds, preferably less than about 50 nanoseconds, more preferably less than about 30 nanoseconds, even more preferably less than about 15 nanoseconds. Scan times of scintillation devices are often related to primary decay time of the scintillator roughly by a factor of 1,000. Thus, a scintillator having a decay time of 1 millisecond will typically produce a scan time of about 1 second. The scanning units containing the present generation of scintillators have scan times on the order of 1 second. Shorter scan times are desired. Shorter scan times may be achievable if the primary decay time of the scanner is shortened. In general, scan time in seconds is associated with a primary decay time of an equal number of milliseconds.

The invention also relates to a process for manufacturing scintillator single crystals having a light yield under gamma excitation of greater than about 10,000 photons per MeV, in which the single crystals produced from the same chemical composition have a relative variation in light yield under identical excitation of less than 50%, comprising at least the following steps:

Supplying raw material powders, for example lutetium oxide (Lu_2O_3) powder, silica (SiO_2) powder, and powder of at least one caesium carrier, for example an oxide (Ce_2O_3), advantageously at predetermined stoichiometric quantities;

Optionally pre-reacting the powders supplied;

Melting of the powders and/or optionally pre-reacted powders at a temperature of less than 2200° C., preferably less than 2100° C., and even more preferably less than 2000° C., in order to obtain a molten composition of general formula
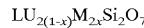
$$LU_{2(1-x)}M_{2x}Si_2O_7$$

where LU is lutetium or a lutetium-based alloy which also includes one or more of the following elements: Sc, Y, In, La, Gd; where M is cerium or cerium partially substituted with one or more of the elements of the lanthanide family (excluding lutetium); and where x is defined by the limiting level of Lu substitution with M in a monoclinic crystal of the lutetium pyrosilicate (LPS) structure;

Growing of a crystal by a floating zone technique or according to the Czochralski method; and

Cooling of the single crystal.

This process is particularly advantageous since the temperatures needed to melt and then grow the LPS crystals are markedly lower, about 200° C. lower, than those needed for growing LSO crystals. Thus, a process is obtained which is less expensive than that needed for the manufacture of LSO

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single crystals. This point is particularly important since the techniques for growing this type of crystal generally require crucibles made of iridium, the melting point of which is 2410° C., into which the raw materials for the melt pool are introduced and heated. It is known that iridium starts to soften around 2100° C., thereby shortening the lifetime of the crucibles used at this temperature. By virtue of the melting point of LPS of about 1900° C., it is possible to considerably reduce the investment and running costs of the crucibles, especially by reducing the thickness of the walls of the crucibles and/or by benefiting from a longer lifetime compared with that of crucibles made to operate at a temperature of around 2100° C. or higher. Further advantages arise owing to the melting point of LPS, about 1900° C., such as, in particular, energy savings and longer lifetimes of the refractories used in the furnaces, compared with the conditions required by a crystal melting at around 2100° C.

The crystal may be annealed in a vacuum of at least about 30 millimeters of mercury pressure, or an atmosphere of an inert gas such as argon, or in an atmosphere of an inert gas such as argon with a reducing gas such as molecular hydrogen. While annealing benefits from extended time, the annealing process can be as short as about 30 minutes.

The invention also relates to a radiation detector, especially for gamma-rays and/or X-rays, containing: a scintillator consisting of a transparent monoclinic single crystal of general formula:
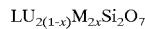
$$LU_{2(1-x)}M_{2x}Si_2O_7$$

where LU is lutetium or a lutetium-based alloy which also includes one or more of the following elements: Sc, Y, In, La, Gd; where M is cerium or cerium partially substituted with one or more of the elements of the lanthanide family (excluding lutetium); and where x is defined by the limiting level of LU substitution with M in a monoclinic crystal of the lutetium pyrosilicate (LPS) structure; a photodetector optically coupled to the scintillator in order to produce an electrical signal in response to the emission of a light pulse produced by the scintillator. The photodetector of the detector may especially any type known in the art, for example a photomultiplier, or a photodiode, or else a CCD sensor.

The preferred use of this type of detector relates to the measurement of gamma-rays or X-rays; such a system is also capable of detecting alpha and beta particles as well as electrons.

According to an advantageous variant, the detector comprises a scintillator of general formula

$$LU_{2(1-x)}M_{2x}Si_2O_7$$
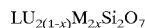
where x is defined by the limiting level of Lu substitution with M in a monoclinic crystal of the lutetium pyrosilicate (LPS) structure. According to another advantageous variant, the detector comprises a scintillator of general formula
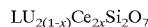
$$LU_{2(1-x)}Ce_{2x}Si_2O_7$$

where x is defined by the limiting level of Lu substitution with Ce in a monoclinic crystal of the lutetium pyrosilicate (LPS) structure.

According to an advantageous variant, the scintillator single crystal has a level of x substitution of less than 0.5 at %, especially less than 0.2 at %, and even less than 0.1 at %. The level of x substitution is advantageously greater than 0.01 at % in some embodiments, and more advantageously greater than about 0.05 at % in some embodiments.

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The invention also relates to the use of the above detector in machines used in nuclear medicine, especially positron emission tomography scanners. According to another variant, the invention relates to the use of the above detector in detection machines for oil drilling.

Further details and characteristics will emerge from the description below of non-limiting preferred embodiments and from data obtained on specimens consisting of single crystals according to the invention.

EXAMPLES

Examples 1–4

Base oxides comprising lutetium oxide powder, silica powder, and Ce_2O_3 were combined at predetermined stoichiometric quantities and were prereacted in the solid state in platinum crucibles in an argon atmosphere, at 1500° C. The temperature was then increased. Crystals were obtained by the floating zone technique in which the single crystals were produced from polycrystalline materials obtained from base oxides. The growth rate was 2 mm/hour and the growth temperature was less than 1900° C. Tests were carried out under various production conditions and the results given in Table 1 demonstrate that the insertion of cerium is possible in an LPS-type crystal, $Lu_2Si_2O_7$.

The initial Ce^{3+} concentration corresponds to the amount of cerium introduced into the melt pool and the final Ce relative percentage corresponds to the percentage of the amount of cerium inserted into the final crystal.

The single crystals obtained were transparent and were characterized by X-ray diffraction analysis. Their structure was that of thorveitite and no parasite phase was detected. The crystal lattice parameters are as follows: a=6.765 angstroms; b=8.839 angstroms; c=4.715 angstroms; B=101.96°; and V=275.9 angstroms^3. It is appreciated by one of ordinary skill in the art that occasional local small variations may be observed in lattice parameters.

TABLE 1

Example	Initial Ce^{3+} conc. in reactants (at %)	Preparation conditions	Ce^{3+} in crystal divided by Ce^{3+} in Example 4
1	1%	air	54%
2	1%	argon	91%
3	0.5%	vacuum	54%
4	0.5%	vacuum and annealing under Ar/H_2 for 12 hours	100%

These values are very close to the known values for the lattice parameters of $Lu_2Si_2O_7$ and suggest that the presence of Ce^{3+} has only a very slight effect on the lattice parameters.

The density of the single crystals obtained was 6.23 grams per cubic centimeter.

The light yield of the cerium-doped LPS crystals is given in Table 2 for several gamma sources.

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TABLE 2

| Examples | Light yield in photons/MeV for the following sources: | |
	^{241}Am	^{137}Cs
2	22,020	
3	16,750	20,720
3a	18,750	21,300
4	19,320	13,200

Example 3a corresponds to a specimen produced under the same conditions as Example 3. Excellent reproducibility in the optical properties is observed and the two crystals differ in light yield by about 10%.

The Ce-doped LPS crystals, denoted Ce:LPS, have a short scintillation decay time, for example about 30 ns.

Example 5

Reactants were premixed and reacted in a manner similar to that described for Examples 1–4. Large single crystals, that is, cylinders 80 mm in length and 25 mm in diameter, were obtained by the Czochralski growth method. These examples had the same crystallographic characteristics as examples obtained by the floating zone technique. They had no parasitic phase.

Example 6

Example 6, containing Ce and Tb, were also obtained by floating zone technique under similar conditions as described for Example 5. These specimens were obtained from a melt pool comprising 0.5 at % Ce^{3+} and 0.5 at % Tb^{3+}. The structure of the LPS was retained. The LPS crystals codoped with Ce and Tb have a lower light yield than that of the Ce-doped LPS crystals but have the advantageous characteristic of a shorter scintillation decay time, especially about 10 ns. It is believed that the scintillation properties show that effective energy transfer between Ce and Tb occurred.

Example 7

Single crystals in which lutetium mixed, or alloyed, with indium, In, were obtained under conditions similar to those used for Example 5. The indium content should be less than 25%, for example less than 20%, of the sum of Lu and In in the melt pool in order to obtain congruent melting. The lattice parameters of the crystal with a Lu:IN ratio of 9:1, that is, a $(Lu_{0.9}In_{0.1})_{2(1-x)}Ce_{2x}Si_2O_7$ crystal are: a=6.767 angstroms; b=8.834 angstroms; c=4.715 angstroms; B=102.01°, and V=275.7 angstroms^3.

These parameters, which are slightly smaller than those for $Lu_{2(1-x)}Ce_{2x}Si_2O_7$, prove the insertion of In into the lattice. The crystal $(Lu_{0.9}In_{0.1})_{2(1-x)}Ce_{2x}Si_2O_7$ has a scintillation decay time of about 60 ns. decay time of about 60 ns.

Example 8

Table 3 shows the physical and properties of the scintillator crystals T1:NaI, BaF2, BGO, Ce-LSO and Ce-LPS families.

The data in Table 3 clearly shows that the LPS constitutes a novel family of scintillator crystals whose emission properties are of the same order of magnitude as those of LSO. Furthermore, the LPS crystals have the additional advantage of not having a slow scintillation decay component.

TABLE 3

Composition:	Prior art T1:NaI	Prior art BaF2	Prior art BGO	Prior art Ce:LSO	Ex. 8 Ce:LPS
Effective atomic number	51	53	74	66	64
Scintillation decay time, ns	230	0.8	300	40	30
Photon yield under gamma excitation	38,000	1400	8000	25,000	>17,000
Emission peak (wavelength, nm)	415	220	480	420	380
Hygroscopic	YES	NO	NO	NO	NO

While the foregoing description represent the preferred embodiments of the present invention, it will be understood that various additions and/or substitutions may be made therein without departing from the spirit and scope of the present invention. One skilled in the art will appreciate that the invention may be used with many modifications of structure, forms, arrangement, proportions, materials, and components and otherwise, used in the practice of the invention and which are particularly adapted to specific environments and operative requirements, without departing from the principles of the present invention. The presently disclosed embodiments are therefore to be considered in all respects as illustrative and not restrictive.

We claim:

1. A monoclinic crystal with a lutetium pyrosilicate structure of the formula
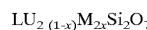
$$LU_{2\,(1-x)}M_{2x}Si_2O_7$$

where LU is lutetium or a lutetium-based alloy of one or more of scandium, yttrium, ytterbium, indium, lanthanum, and gadolinium; where M is cerium or cerium partially substituted with one or more of the elements of the lanthanide family excluding lutetium; and where x is defined by the limiting level of LU substitution with M in a monoclinic crystal of the lutetium pyrosilicate structure, and wherein the crystal has at least two dimensions each greater than 3 mm.

2. The crystal of claim **1** wherein LU consists essentially of lutetium.

3. The crystal of claim **1** wherein M consists essentially of cerium.

4. The crystal of claim **1** wherein x is between about 0.01 at % and about 0.5 at %.

5. The crystal of claim **1** wherein x is less than about 0.2 at %.

6. The crystal of claim **1** wherein x is less than about 0.1 at %.

7. The crystal of claim **1** wherein x is greater than about 0.05 at %.

8. The crystal of claim **1** wherein the crystal lattice parameter a is between about 6.76 and about 6.77 angstroms, b is between about 8.83 and about 8.84 angstroms, c is between about 4.71 and about 4.72 angstroms, and B is between about 101.9° and 102.10.

9. The crystal of claim **1** wherein the crystal has a light yield under gamma excitation of greater than about 10,000 photons per MeV, wherein the crystal was obtained by crystallization of a congruent molten composition, and wherein the light yield is within 50% of the light yield of other crystals crystallized in the same manner from congruent melts with the same composition.

10. The crystal of claim **9** wherein the light yield that is within about 20% of the light yield of other crystals crys-

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tallized in the same manner from congruent melts with the same composition.

11. The crystal of claim 1 wherein LU is a lutetium based alloy comprising lutetium and yttrium, and wherein the lutetium based alloy contains at least about 75 weight percent of lutetium.

12. The crystal of claim 1 wherein the crystal when excited by gamma radiation emits photons, and wherein the emission of photons decays in less than about 70 nanoseconds.

13. The crystal of claim 1 wherein the crystal when excited by gamma radiation emits photons, and wherein the emission of photons decays in less than about 50 nanoseconds

14. The crystal of claim 1 wherein the crystal when excited by gamma radiation emits photons, and wherein the emission of photons decays in less than about 30 nanoseconds.

15. The crystal of claim 1 wherein the crystal when excited by gamma radiation emits photons, and wherein the emission of photons decays in less than about 15 nanoseconds.

16. The crystal of claim 1 wherein M comprises cerium and terbium.

17. The monoclinic crystal of claim 1 wherein LU is a lutetium-based alloy comprising lutetium and scandium.

18. The monoclinic crystal of claim 1 wherein LU is a lutetium-based alloy comprising lutetium and yttrium.

19. The monoclinic crystal of claim 1 wherein LU is a lutetium-based alloy comprising lutetium and ytterbium.

20. The monoclinic crystal of claim 1 wherein LU is a lutetium-based alloy comprising lutetium and indium.

21. The monoclinic crystal of claim 1 wherein LU is a lutetium-based alloy comprising lutetium and lanthanum.

22. The monoclinic crystal of claim 1 wherein LU is a lutetium-based alloy comprising lutetium and gadolinium.

23. The monoclinic crystal of claim 1 wherein M comprises cerium and terbium.

24. A process for manufacturing scintillator crystals comprising:

supplying a lutetium containing reactant, a silica containing reactant, and a cerium containing reactant;

melting the reactants at a temperature below about 2200° C. to form a congruent molten composition; and

crystallizing a crystal from the congruent molten composition, wherein the crystal has the composition

$$LU_{2(1-x)}M_{2x}Si_2O_7$$

in a lutetium pyrosilicate structure, where LU is lutetium or a lutetium-based alloy of one or more of scandium, yttrium, ytterbium, indium, lanthanum, and gadolinium; where M is cerium or cerium partially substituted with one or more of the elements of the lanthanide family excluding lutetium; and where x is defined by the limiting level of LU substitution with M in a monoclinic crystal of the lutetium pyrosilicate structure, and wherein the crystal has at least two dimensions each greater than 3 mm.

25. The process of claim 24 wherein the lutetium containing reactant comprises lutetium oxide powder, the silica containing reactant is silica powder, and the cerium containing reactant is cerium oxide, and wherein the reactants melt at a temperature below about 2100° C. to form a congruent molten composition.

26. The process of claim 24 wherein the reactants melt at a temperature below about 2000° C. to form a congruent molten composition.

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27. The process of claim 24 wherein the reactants melt at a temperature below about 1900° C. to form a congruent molten composition.

28. The process of claim 24 further comprising pretreating the supplied reactants by heating the reactants to a temperature of at least about 1500° C. under an atmosphere comprising a vacuum of at least about 30 millimeters of mercury pressure, or an atmosphere comprising argon.

29. The process of claim 24 further comprising annealing the composition under an atmosphere comprising molecular hydrogen for a period of at least about 30 minutes.

30. The process of claim 24 wherein the crystallizing the crystal from the congruent molten composition is completed by the floating zone technique.

31. The process of claim 24 wherein the crystallizing the crystal from the congruent molten composition is completed by the Czochralski method.

32. The process of claim 24 wherein the single crystals produced from the same congruent molten compositions have a relative variation in light yield under excitation from a gamma ray of less than 50%.

33. A monoclinic scintillator crystal of the lutetium pyrosilicate structure obtained by the process of claim 24.

34. A radiation detector comprising:

a scintillator comprising a crystal of the composition
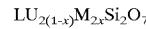
$$LU_{2(1-x)}M_{2x}Si_2O_7$$

where LU is lutetium or a lutetium-based alloy of one or more of scandium, yttrium, ytterbium, indium, lanthanum, and gadolinium; where M is cerium or cerium partially substituted with one or more of the elements of the lanthanide family excluding lutetium; and wherein x is defined by the limiting level of LU substitution with M in a monoclinic crystal of the lutetium pyrosilicate structure, wherein the crystal when excited by gamma radiation emits photons, and wherein the emission of photons decays in less than about 70 nanoseconds; and

photodetector optically coupled to the scintillator in order to produce an electrical signal in response to the emission of said photons by the scintillator.

35. The radiation detector of claim 34 wherein LU consists essentially of lutetium.

36. The radiation detector of claim 35 wherein M consists essentially of cerium, and wherein x is less than 0.5 at %.

37. The detector of claim 34 operably connected to nuclear medicine machines.

38. The detector of claim 34 operably connected to a well logging tool.

39. The radiation detector of claim 34 wherein consists essentially of lutetium.

40. The radiation detector of claim 34 wherein x is between about 0.01 at % and about 0.5 at %.

41. The radiation detector of claim 34 wherein x is less than about 0.2 at %.

42. The radiation detector of claim 34 wherein x is less than about 0.1 at %.

43. The radiation detector of claim 34 wherein x is greater than about 0.05 at %.

44. The radiation detector of claim 34 wherein two dimensions of the crystal are each greater than about 5 mm.

45. The radiation detector of claim 34 wherein two dimensions of the crystal are each greater than about 10 mm.

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46. The radiation detector of claim **34** wherein the crystal has a light yield under gamma excitation of greater than about 10,000 photons per MeV.

47. The radiation detector of claim **34** wherein LU consists essentially of lutetium and yttrium and contains at least about 75 weight percent of lutetium.

48. The radiation detector of claim **34** wherein the crystal when excited by gamma radiation emits photons, and wherein the emission of photons decays in less than about 50 nanoseconds.

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49. The radiation detector of claim **34** wherein the crystal when excited by gamma radiation emits photons, and wherein the emission of photons decays in less than about 30 nanoseconds.

50. The radiation detector of claim **34** wherein the crystal when excited by gamma radiation emits photons, and wherein the emission of photons decays in less than about 15 nanoseconds.

51. The radiation detector of claim **34** wherein M comprises cerium and terbium.

*   *   *   *   *

EXHIBIT 4

US006624420B1

(12) **United States Patent**
Chai et al.

(10) **Patent No.:**   **US 6,624,420 B1**
(45) **Date of Patent:**   **Sep. 23, 2003**

(54) **LUTETIUM YTTRIUM ORTHOSILICATE SINGLE CRYSTAL SCINTILLATOR DETECTOR**

(75) Inventors: **Bruce H. T. Chai**, Oviedo, FL (US); **Yangyang Ji**, Orlando, FL (US)

(73) Assignees: **University of Central Florida**, Orlando, FL (US); **Crystal Photonics, Inc.**, Sanford, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/506,160**

(22) Filed: **Feb. 17, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/120,500, filed on Feb. 18, 1999.

(51) **Int. Cl.^{7}** **G01T 1/202; C09K 11/08**
(52) **U.S. Cl.** .... **250/361 R**; 252/301.4 F
(58) **Field of Search** .... 250/361 R; 252/301.4 F

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Primary Examiner—Constantine Hannaher
(74) *Attorney, Agent, or Firm*—Brian S. Steinberger; Law Offices of Brian S. Steinberger

(57)   **ABSTRACT**

A single crystal having the general composition, $Ce_{2x}(Lu_{1-y}Y_y)_{2(1-x)}SiO_5$ where x=approximately 0.00001 to approximately 0.05 and y=approximately 0.0001 to approximately 0.9999; preferably where x ranges from approximately 0.0001 to approximately 0.001 and y ranges from approximately 0.3 to approximately 0.8. The crystal is useful as a scintillation detector responsive to gamma ray or similar high energy radiation. The crystal as scintillation detector has wide application for the use in the fields of physics, chemistry, medicine, geology and cosmology because of its enhanced scintillation response to gamma rays, x-rays, cosmic rays and similar high energy particle radiation.

17 Claims, 5 Drawing Sheets

SCINTILLATING DETECTORS

Ce^{3+}: LYSO CRYSTAL	PHOTOMULTIPLYER OR OTHER PHOTO-DETECTOR

Ce^{3+}: Y$_2$SiO$_5$ ABSORPTION AND EMISSION SPECTRA

EMISSION CROSS SECTION (10^{-18} cm^2)

ABSORPTION CROSS SECTION (10^{-18} cm^2)

WAVELENGTH (nm)

FIG. 1A (YSO)

Ce^{3+} : Lu$_2$SiO$_5$ ABSORPTION AND EMISSION SPECTRA

FIG. 1B (LSO)

SCINTILLATING DETECTORS

Ce^{3+}: LYSO CRYSTAL

PHOTOMULTIPLYER OR OTHER PHOTO-DETECTOR

FIG. 2

FIG. 3

EFFECTIVE Z AS A FUNCTION OF Lu IN LYSO

% OF Lu IN LYSO

FIG. 4

EFFECTIVE Z
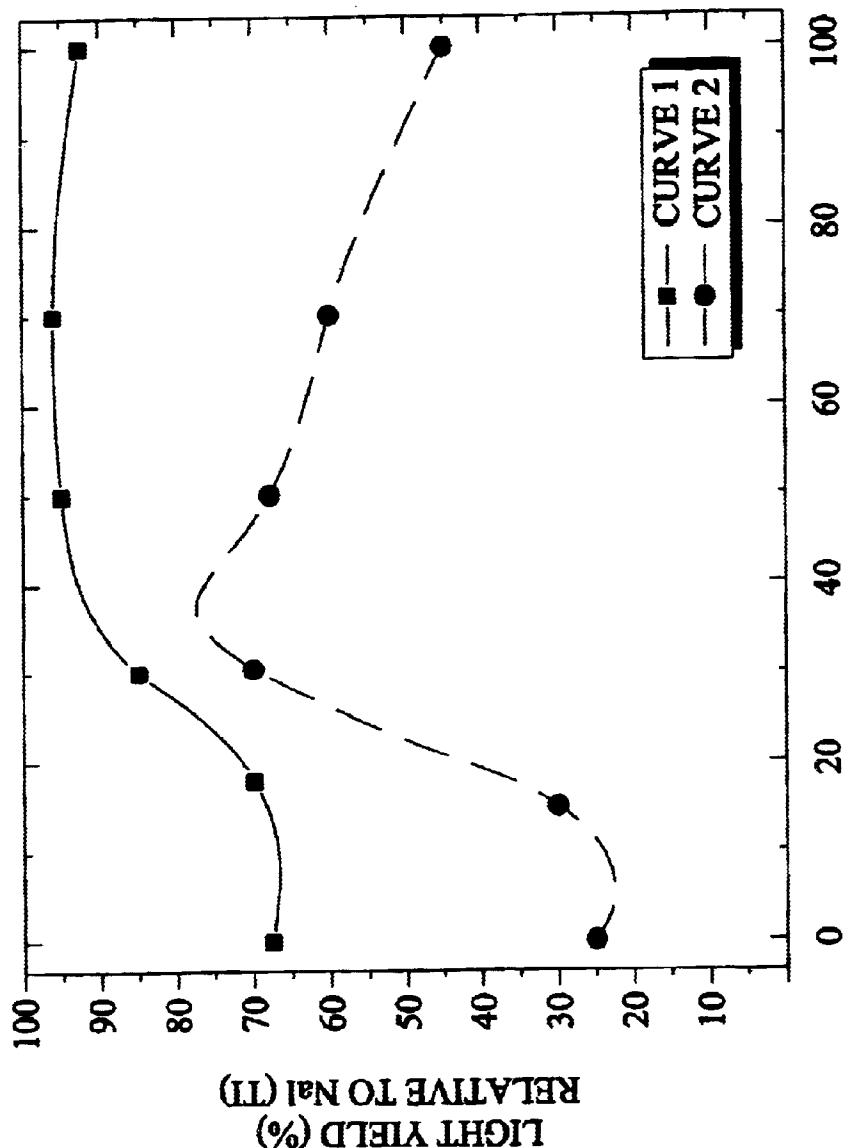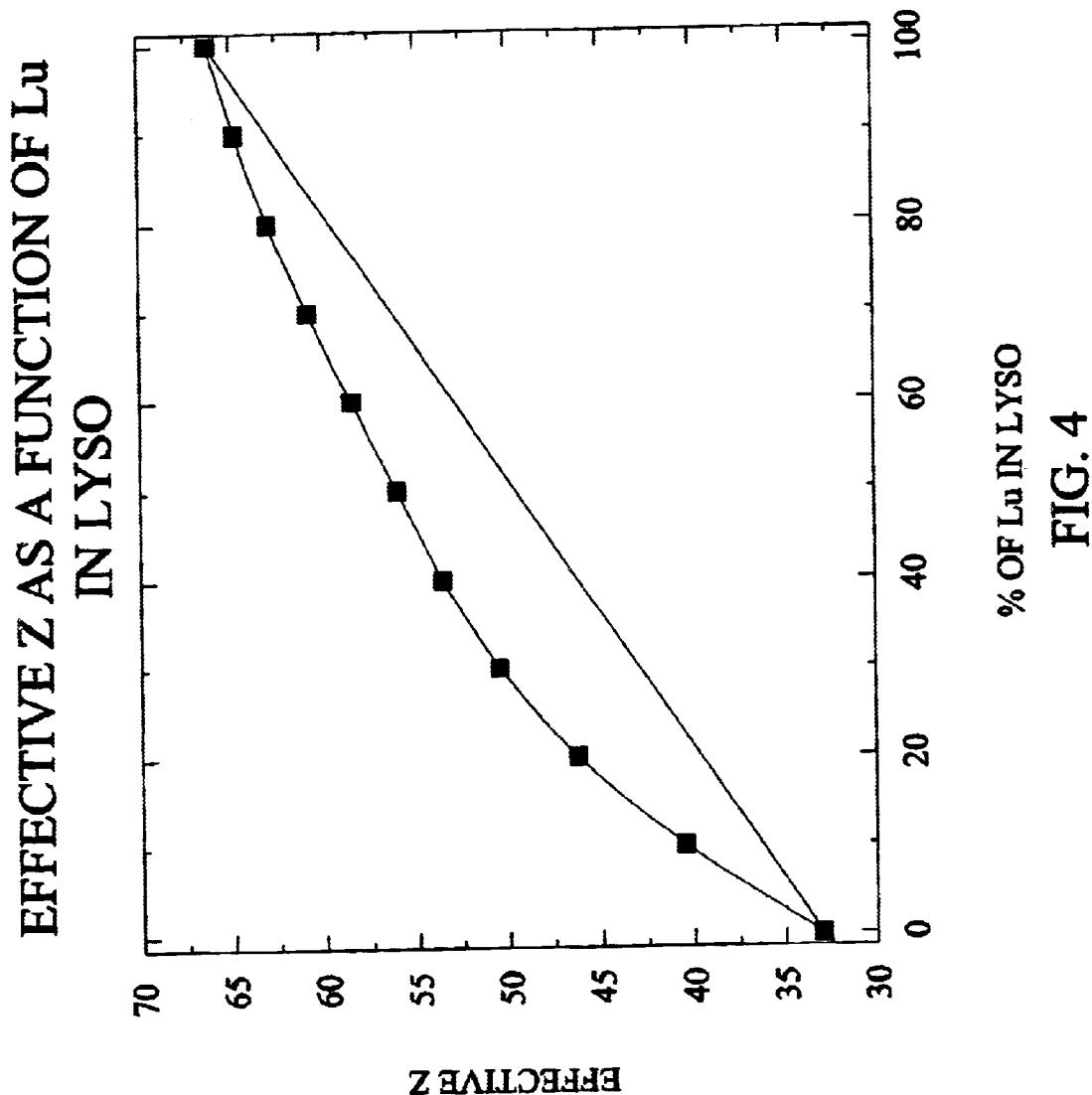
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LUTETIUM YTTRIUM ORTHOSILICATE SINGLE CRYSTAL SCINTILLATOR DETECTOR

This application claims priority based on U.S. Provisional Application Serial No. 60/120,500 filed Feb. 18, 1999. This invention relates to a single crystal as scintillating detector for gamma ray or similar high energy radiation which single crystal is composed of Cerium doped Lutetium Yttrium orthosilicate (LYSO) with the general composition of $Ce_{2x}(Lu_{1-y}Y_y)_{2(1-x)}SiO_5$ where x=0.00001 to 0.05 and y=0.0001 to 0.9999.

BACKGROUND AND PRIOR ART

There are a number of ways to detect high energy radiation. Some of the equipment can be quite bulky, such as a cloud chamber, others may not be as sensitive or quantative. Scintillator is a very simple but also very accurate method to detect high energy radiation such as x-rays, gamma-rays, high energy particles exceeding a few kilo-electron-volts (KeV) in energy. When high energy radiation strikes on a scintillating crystal, it creates a large number of electron-hole pairs inside the crystal. Recombination of these electron-hole pairs will release energy in the range of a few eV. This energy can be emitted directly from the recombination center as light or transferred to a light emitting ion center which then emits a specific wavelength of light. This low energy emission can then be detected by a photomultiplier tube, avalanche photo diode (APD) or other detector systems with sufficient sensitivity. The higher the light emission (or light yield), the easier for the detector design.

A The first scintillating crystal is calcium tungstate ($CaWo_4$) which was used before the turn of this century to detect x-rays. The most significant discovery of a scintillating crystal is Thallium-activated sodium iodide NaI(Tl)) in the mid-40's. Even now, it is still the most widely used scintillating crystal. This is because large size crystals are readily available and quite inexpensive. Moreover, the light yield is the highest among all the known materials and is still the benchmark standard for all other scintillator crystals even after all these years. Even though NaI(Tl)) is widely used, it is not without problems. It is hygroscopic and very soft. Moreover, the density is too low (37 g/cm^3), the effective mass number (Z_{eef}) of 49 is also too small. It has a large and persistent after glow which interferes with the intensity counting system. Finally, the decay time about of 230 nanoseconds (ns) is too slow for many applications.

Since the turn of this century, a large number of crystals have been proposed for potential scintillating applications. Even though they do show scintillating properties, none of them has all the right properties. The common problems are low light yield, physical weakness and difficult to produce large size high quality single crystals. Despite the problems, a number of them have found applications in physics, chemistry, geology and medicine. One common feature of all these usable crystals is that they are the only crystals which can be produced in large size and high quality by an industrial manufacturing process with reasonable cost. This common feature has proven to be the most important factor, more so than the details of scintillating properties, to be considered as a viable scintillator material. The specific examples include bismuth germanate ((BGO) which is $Bi_4Ge_3O_{12}$), cerium doped gadolinium orthosilicate ((GSO) which is Gd_2SiO_5) and cerium doped lutetium orthosilicate ((LSO) which Lu_2SiO_5).

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BGO was found in the early 70's. It has higher density (7.13 g/cm^3), and is non-hygroscopic. But it also has problems such as low light yield (15% that of NaI(Tl)), slow decay time (300 ns) and high refractive indices (n=2.15) which results in light loss due to internal reflection. Still BGO scintillator crystals are now used in high energy calorimetry in particle physics research Institutes. It is also used as the detector for the 511 keV gamma-ray radiation of the positron emission tomographs (PET) in medical imaging application. Because of the low light and slow decay, the image produced from the BGO PET machine tends to be blurred with poor resolution.

In early 80's, the Ce doped GSO crystal was disclosed as a scintillator material. It has adequate density (6.71 g/cm^3) and is also non-hydrogroscopic. The light yield is 20% of that obtained with NaI(Tl) with a much faster decay time (60 ns). Even though GSO crystals over 80 mm diameter have been produced, the crystal has not yet made in the PET marker because of a strong cleavage plane. It is very difficult to cut and polishing the crystal into any specific shape without the risk of fracturing of the entire crystal. Another unexpected problem is the high thermal neutron capture cross-section (49,000 barns) of the gadolinium. It will interfere with the gamma rays generated by neutron irradiation source. However, since there is no neutron involved in the PET process, gadolinium containing GSO is not a problem.

In the late 80's, the Ce doped LSO crystal was disclosed as a good scintillator material. Similar to GSO, it has high density (7.4 g/cm^3) and is non-hygroscopic. The light yield is significantly better and close to 75% that of NaI(Tl)) and the decay time is even faster (42 ns). The index of refraction is also very low (n=1.82). Moreover, since LSO has a totally different crystal structure from GSO, it is fortuitous that in LSO structure, there is not any distinct cleavage plane making the material more suitable for detector block fabrication without the serious risk of fracturing. The thermal neutron capture cross-section is very low (84 barns) as compared to GSO. Lastly, it is now possible to commercially produce high quality, large size single crystals of LSO. Compared with all the other existing known scintillator crystals, Ce doped LSO seems to have the best combination of all the needed properties for PET or other high energy gamma-ray detector application.

Unfortunately, the lutetium element of the crystal contains a trace amount of a natural long decay radioactive isotope, Lu^{176}, which will provide some background count rate that can be harmful for certain highly sensitive detector applications and the crystal has very deep trap centers. This is evidenced by the very long phosphorescence after exposure to any UV light source. The light output measurement of a large number of LSO crystals shows an anti-correlation between trap-related integrated thermoluminescence output and scintillation light output over a range of several orders of magnitude. At present time, the crystal defect is the most serious issue. One can have two crystals with identical appearance with one having 100% light yield and the other failing to scintillate. Thus far, there is no understanding how these deep traps are formed in the first place and there is also no remedy how to reduce or eliminate them.

At present, the scintillation process has been well accepted and used in many applications. The basic mechanism is also reasonably well understood. It is generally accepted that the basic scintillation process involves three steps: (1) the absorption of the incident high energy radiation and the conversion into a large number of low energy (a few multiples of the band gap energy) electrons and hole pairs;

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(2) transfer the electron-hole recombination energy to the luminescence centers before its loss to multi-phonon relaxation processes; and, (3) the radiative emission of the transferred energy. In other word, the scintillation efficiency (E) can be expressed as:

$$E = \beta \times S \times Q$$

where β is the conversion efficiency, S is the transfer efficiency and Q is quantum efficiency of the radiation centers. Despite the understanding of scintillating mechanism based on the known materials, there is still lack of any good model which has the capability to predict the scintillating behavior of a specific compound. The quantum efficiency of an emission center can be predicted and tested optically; however, neither the total number of electron-hole pairs generated by an incident gamma ray radiation nor the transfer efficiency can be predicted or independently tested. In the end, the only way to confirm the scintillating behavior of a compound is to make and then test it.

SUMMARY OF THE INVENTION

The first objective of the present invention is to provide a scintillation detector for use as a high-energy radiation detector.

The second objective of this invention is to provide an improved scintillation crystal for use as a gamma ray or other high energy radiation detector.

The third objective of this invention is to provide a monocrystalline scintillation crystal of improved performance for use as a gamma ray or other similar high energy radiation detector.

In the subject invention, an improved scintillation detector assembly has been realized comprising: a cerium doped lutetium yttrium orthosilicate crystal; and, a photodetector coupled to said crystal whereby an electrical signal is generated in response to a light pulse from said crystal when exposed to a high energy gamma ray. The crystal is preferably monocrystalline and of a general composition of $Ce_{2x}(Lu_{1-y}Y_y)_{2(1-x)}SiO_5$ where x=0.00001 to 0.05 and y=0.0001 to 0.9999 whereby the detector utilizing said crystal as the scintillator responsive to gamma and other similar high energy radiation is particularly useful in the fields of physics, chemistry, geology and cosmology.

BRIEF DESCRIPTION OF THE FIGURES

FIGS. 1a and 1b shows absorption and emission spectra of pure YSO and LSO.

FIG. 2 is a pictoral representation of a typical cerium doped LYSO scintillating detector.

FIG. 3 shows the LYSO scintillating light yield intensity as a function of lutetium concentration.

FIG. 4 shows the change of effective Z of LYSO as a function of lutetium concentration.

DESCRIPTION OF REPRESENTATIVE EMBODIMENT

For illustrative purpose, a representative embodiment of the invention is described hereinafter in the context for the detection of high energy gamma rays. It will be understood that the LYSO single crystal scintillator of the invention is not limited to the detection of gamma ray radiation but it has the general application for the detection of other types of radiation such as x-rays, cosmic and other high energy particle rays.

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In the background review, it is mentioned that Ce doped LSO has the best scintillating properties among all the known materials. But is still has a few serious problems to over come; namely, the isotope problem and the defect (deep trap) problem. In addition to these physical issues, LSO crystals also face two tough economic issues. First is the high melting temperature for growth. The melting point of LSO is estimated around 2200° C. It is among the highest melting temperature crystals produced commercially. Special high temperature ceramics were used to build the furnace and Iridium crucibles were used to contain the melt for growth. The growth process is quite detrimental to both insulation and the crucible. High cost of frequent replacement of the hardware pushes cost too high to be bearable for practical use. Second is the high cost of raw material of lutetium oxide. It is not a common material. Moreover, the current material purity around 99.99% is not sufficient to guarantee consistent high light yield. It is highly desirable to reduce or even replace lutetium oxide as the main ingredient in new scintillator crystals.

The embodiment of this invention is to design a new crystal which can eliminate most of the problems of LSO crystal with sacrifice the scintillating properties. Our initial motivation is to reduce the growth temperature of LSO single crystals. It is a very difficult task to maintain the operation at such high temperature for long period of time (<1 week). Since YSO has lower melting temperature near 2070° C., we are seeking the possibility to find an intermediate composition (or LYSO composition) which may melt at lower temperature to ease the growth process. We also want to minimize the yttrium content to retain the LSO scintillating properties.

Since there is no known published phase diagram between YSO and LSO, the phase relationship of the intermediate composition is not available. We speculate the melting and crystallization behavior of the intermediate LYSO crystal composition based on two assumptions. First, since both YSO and LSO have the same crystallographic structure and the ionic size of yttrium 3+ion (0.090 nm) and lutetium 3+ion (0.088 nm) are very similar, we assume that there is a 100% miscibility between the m'o compositions. In other word, it is possible to make any intermediate composition LYSO crystals without worry about phase separation or formation of new compounds. Second, since YSO has lower melting temperature, based on the model of ideal solid solution, it is expected that all the intermediate compositions will have lower melting temperature similar to the classic example of fosterite (Mg_2SiO_4)-fayalite (Fe_2SiO_4) pseudo-binary phase relations even though the exact position of the solidus and liquidus lines are not known.

In order to understand the melting and crystallization behavior, four intermediate LYSO charge compositions were prepared. The compositions were: $Ce_{0.002}(Lu_{0.7}Y_{0.3})_{1.998}Si_2O_5$ designate (70% LYSO); $Ce_{0.002}(Lu_{0.5}Y_{0.5})_{1.998}Si_2O_5$ designated (50% LYSO); $Ce_{0.002}(Lu_{0.3}Y_{0.7})_{1.998}Si_2O_5$ designated (30% LYSO); and, $Ce_{0.002}(Lu_{0.15}Y_{0.85})_{1.998}Si_2O_5$ designated as (15% LYSO). The percentage refer the fraction of the lutetium in the crystal. A pure LSO charge was also prepared to be processed in a similar way as a reference for direct comparison. To make sure that the property comparison is meaningful, all the LYSO crystal preparation procedures are identical. The same total number of moles of chemicals in each case were used so that the finished crystals are near identical in size. To minimize the repetition, the 70% LYSO composition is hereafter set forth as the example to illustrate the preparation for all examples:

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A mixture of high purity fine powders consisting of 1476 grams of Lu_2O_3, 359 grams of Y_2O_3, 317 grams of SiO_2 and 3.6 grams of CeO_2 were mechanically mixed thoroughly. The purity of Lu_2O_3 is 99.99%. The purity of both Y_2O_3 and SiO_2 is 99.9999.

(2) The mixed charge is placed in a 75 mm diameter by 75 mm deep iridium metal crucible and melted in a 50 kilowatt maximum power radio frequency (RF) heated high temperature furnace.

(3) When the charge is fully molten and stabilized at near the melting temperature, a pure LSO seed crystal is lowered into the furnace and touched to the top center of the melt surface and the system is let to equilibrate.

(4) Once the seed is in equilibrium with the melt, the seed is pulled up slowly with rotation. A computer controlled automatic diameter controlled program is used to finish the growth to a crystal diameter of 30 mm while using a pull rate of 1.5 mm per hour.

(5) When the crystal has reached the desired length, it is separated from the melt and let cool slowly in the furnace to room temperature. The crystal is then recovered from the furnace and cut to smaller pieces for evaluation.

In order to check the melting behavior, an oversized crystal was grown in order to convert the maximum amount of melt to crystal. The resulting 30% LYSO crystal had a total length of 32 cm and a total weight of 1880.5 grams. The crystal took 8 days to complete the growth. In this case, the bottom 5 cm portion of the crystal contains a lot of visual inclusions and defects and thus was not usable for evaluation. It did, however, provide important information on the stability range of the melt.

Five crystals were grown consecutively in the same crucible and furnace at near identical growth conditions. There appeared to be no difference in crystal quality among all the five crystals. More interestingly, the fraction of the usable melt seems also to be quite the same regardless of the lutetium to yttrium ratio. This allows adjusting the crystal composition to best fit any specific application. In addition to the compositional flexibility, there was a significant lowering of the melting temperature which facilitates growth of these crystals.

To evaluate the scintillating properties, two 10 mm slabs were cut from each crystals, one from the top of the crystal and one from the bottom right above the defect region. It has been found that the scintillating light yield of any LSO crystal decreases systematically form the top to the bottom of the boule. The relative light yield can vary by as much as a factor of 2. It appears that this is due to the impurities in the lutetium oxide (Lu_2O_3) source material. Since the LYSO also uses the same Lu_2O_3 starting material, the LYSO will also show the same behavior.

The slab is placed under a Na^{22} radiation source which generates the 511 keV gamma ray as the incident light. The scintillating light from the LYSO slab is captured by a Hamamatsu R877 photomultiplier. The scale used for the light output measurement is arbitrary unit. In this case, the light output for a standard NaI(Tl) scintillator is set a 100%. In comparison, the standard BGO crystal has a light output of 12.5%. The energy resolution is expressed as the full width at half maximum of the 511 keV gamma ray peak. The result of the measurement is summarized in Table 1 and plotted in FIG. 3.

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TABLE 1

	YSO	15% LYSO	30% LYSO	50% LYSO	70% LYSO	LSO
Light yield %						
(top)	68	70	85	94	96	93
(bottom)	24	28	71	67	60	46
Energy Resolution %						
(top)	12	9	9	9	8	10
(bottom)	21	18	13	11	13	16
Effective Z	33	44	52	58	63	66
Density	4.62	5.04	5.45	6.01	6.57	7.4
Radiation length (cm)	9.5	4.5	2.3	1.6	1.2	1.1
Phosphorescence	No	No	No	very weak	weak	Yes

Fist, the top portion of each crystal has the best scintillating value n since the crystallization process has been found to be a purification process. The first (top) portion the result has many important implications of a crystal will have the least impurity content and thus the best performance. It is interesting to notice that the pure LSO crystal has produced light yield of 93% of that of NaI(Tl). This is significant higher than the published result of 75%. This value may approach to the ultimate scintillating power for LSO.

Second, simply because of the top portion of each crystal has the highest purity, these measured values are good gauges for the comparison of the ultimate scintillating efficiency of these crystals. The light yield (or scintillating efficiency) remains constant for at least 50% percent substitution of lutetium with yttrium. Degradation of the light yield occurs after 70% replacement of lutetium. All the samples are of approximately equal thickness of 1 cm with no correction imposed for the reduction of density or effective Z. The scintillating efficiency drops rapidly with further addition of yttrium and the Compton signal rises rapidly with more than 85% substitution. The simple conclusion can be drawn that LYSO is a valuable and very efficient scintillator as long as the crystal contains more than 30% lutetium.

Third, the result also shows the rapid reduction of the light yield as the growth is progressing and the greater fraction of the melt is converted to crystal. This is consistent with all the published speculation that impurities are the primary cause to create the deep trap, which gives the long phosphorescence and reduces the scintillating light yield. In the case of pure LSO, the light yield drops by a factor of 2 when 80% of the melt is converted to crystal. This is the largest drop as compared to all the other LYSO crystals.

In FIG. 3, it is shown that there is a linear reduction of light yield for the bottom portion of the LYSO and LSO crystals with linear increasing of lutetium content. This is the most direct evidence to show that the impurity is coming from the Lu_2O_3 starting material. The phosphorescence is greatly reduced with more yttrium substitution and is nearly unnoticed beyond 50% substitution.

In addition to the advantage directly observed from the light yield measurements, LYSO also resolves other problems associated with pure LSO. First the growth temperature of LYSO is lower than that of pure LSO be approximately 100° C. which is very significant in high temperature processes. Since the radiation heat loss is proportional to the 4th power of temperature (or Tn) the high temperature insulation and iridium crucible will last longer. Second, substituting yttrium will reduce proportionally the trace concentra-

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tion of the naturally radioactive Lu^{176} isotope without sacrificing the net light yield. This will, in effect, reduce the background noise of the detector. Third, both the cost and purity of the Lu_2O_3 starting material is a serious issue. Thus, yttrium substitution will reduce the cost and improve the uniformity of scintillating efficiency for large single crystal plates. Further, since a low index of refraction is preferred for scintillating crystals to reduce the effect of total internal reflection, the substitution of yttrium reduces the already low value of the index of refraction of LSO.

Lastly, let us examine the issue of stopping power, radiation length and effective Z. For practicality, it is desirable to use material with highest Z and shortest radiation length. Interesting enough, we find that in the case of LYSO, the effective Z increases rapidly with small substitution of lutetium. It will eventually slow down when it approaching to 100% substitution. FIG. **4** illustrates such effect. As a consequence, 30% LYSO has the same effective Z as NaI (Tl) and 60% LYSO has the same effective Z as GSO. In terms of the radiation length, we can save 30% lutetium with 10% increase of radiation length, save 50% and 70% lutetium with 1.5 and 2 times that of pure LSO. In other words, the reduction is not linear to the substitution. In fact, it is favor for the substitution.

FIG. **2** illustrates the structure of the scintillation device with the crystal of the invention optically connected to the photomultiplier or other photon detector, which can include a photomultiplier tube, a PIN diode, and an APD(avalanche photo detector) diode.

While the invention has been described, disclosed, illustrated and shown in various terms of certain embodiments or modifications which it has presumed in practice, the scope of the invention is not intended to be, nor should it be deemed to be, limited thereby and such other modifications or embodiments as may be suggested by the teachings herein are particularly reserved especially as they fall within the breadth and scope of the claims here appended.

We claim:

1. A scintillator detector for high energy radiation comprising: a monocrystalline structure of cerium doped lutetium yttrium orthosilicate, $Ce_{2x}(Lu_{1-y}Y_y)_{2(1-x)}SiO_5$ where x=approximately 0.0001 to approximately 0.05 and y=approximately 0.0001 to approximately 0.9999.

2. The crystal of claim **1** wherein x ranges from approximately 0.0001 to approximately 0.001 and y ranges from approximately 0.3 to approximately 0.8.

3. A scintillation detector assembly comprising:

a cerium doped lutetium yttrium orthosilicate mono crystal; and,

a photon detector coupled to said crystal, wherein an electrical signal is generated from the photon detector in response to said crystal being exposed to a high energy gamma ray.

4. The detector assembly of claim **3** wherein said mono crystal has the general composition of $Ce_{2x}(Lu_{1-y}Y_y)_{2(1-x)}SiO_5$ where x=approximately 0.00001 to approximately 0.05 and y=approximately 0.0001 to approximately 0.9999.

5. The detector assembly of claim **4** where in x ranges from approximately 0.0001 to approximately 0.001 and y ranges from approximately 0.3 to approximately 0.8.

6. The detector assembly of claim **3** wherein said coupled photon detector is selected from at least one of a photomultiplier tube, a PIN diode and an APD(avalanche photo detector) diode.

7. A method of detecting energy with a scintillation detector, comprising the steps of:

receiving radiation by a crystal comprising cerium doped lutetium yttrium orthosilicate; and

detecting photons with a photon detector coupled to the crystal.

8. The method of claim **7**, wherein the step of receiving radiation includes the step of: receiving gamma rays.

9. The method of claim **7**, wherein the step of receiving radiation includes the step of: receiving x-rays.

10. The method of claim **7**, wherein the step of receiving radiation includes the step of: receiving cosmic rays.

11. The method of claim **7**, wherein the step of receiving radiation includes the step of: receiving radiation by a monocrystaline.

12. The method of claim **7**, wherein the step of detecting includes the step of: detecting light with a photo detector coupled to the crystal.

13. The method of claim **12**, wherein the step of detecting includes the step of: detecting light with a photomultiplier tube coupled to the crystal.

14. The method of claim **12**, wherein the step of detecting includes the step of: detecting light with a PIN diode coupled to the crystal.

15. The method of claim **12**, wherein the step of detecting includes the step of: detecting light with a APD diode coupled to the crystal.

16. The method of claim **7**, wherein the crystal includes a composition of $Ce_{2x}(Lu_{1-y}Y_y)_{2(1-x)}SiO_5$ where x=approximately 0.00001 to approximately 0.05 and y=approximately 0.0001 to approximately 0.9999.

17. The method of claim **16**, wherein x ranges from approximately 0.0001 to approximately 0.001 and y ranges from approximately 0.3 to approximately 0.8.

*   *   *   *   *

EXHIBIT 5

26 April 2006   **Lord Mc Ewan**

The Lord Ordinary, on the unopposed motion of the Pursuer, Interpones
authority of the Court to Joint Minute, No. 17 of process, and in terms thereof
(1) Grants interdict against the first defender, its servants, agents or anyone
acting on its behalf or under its instruction: (a) from infringing Claims 1 and 2
of the Patent in any manner whatsoever; (b) in particular and without
prejudice to the generality of the foregoing, from making, disposing of,
offering to dispose of, using or keeping for disposal or otherwise (i) a cerium-
doped lutetium yttrium oxyorthosilicate scintillator crystal; or (ii) any other
scintillator for use in a gamma ray or x-ray detector comprising: (a) a
transparent single crystal of cerium-activated lutetium oxyorthosilicate having
the general formulation $Ce_{2x}Lu_{2(1-x)}SiO_5$ where x is within the range of from
approximately $2x10^{-4}$ to approximately $3x10^2$; and/or (b) a transparent
singlr crystal of cerium-activated lutetium oxyorthosilicate having the general
formulation $Ce_{2x}Lu_{2(1-x)}SiO_5$ wherein x is within the range of approximately
$1x10^{-3}$ to approximately $4.5x10^{-3}$; and (iii) from causing, authorising,
inducing, facilitating, assisting, procuring or enabling any person to infringe
Claims 1 and 2 of the Patent in any manner whatsoever. (2) Grants interdict
against the first defender, its servants, agents or anyone acting on its behalf
or under its instruction (a) from infringing Claim 3 of the Patent in any
manner whatsoever; (b) in particular and without prejudice to the generality
of the foregoing, from supplying or offering to supply in the United Kingdom
any person other than the pursuer or second defender or other persons
entitled to work the invention claimed in Claim 3 of the Patent with the means
relating to any essential element of that invention for putting that invention
into effect, in particular from supplying or offering to supply such persons
with crystals falling within the scope of Claims 1 or 2 of the Patent including
cerium-doped lutetium yttrium oxyorthosilicate scintillator crystals; and (c)
from causing, authorising, inducing, facilitating, assisting, procuring or
enabling any person to infringe Claim 3 of the Patent in any manner
whatsoever. (3) Grants decree of dismissal in favour of the second defender.
(4) Subject to decree being pronounced in terms of paragraphs 1, 2 and 3
above and without prejudice to any existing awards of expenses, finds no
expenses due to or by any party; and decerns.

Author: jlynn   Page 1 of 2

EXHIBIT 6

FULLY REDACTED

EXHIBIT 7

a winning combination

Two Americans working in the Alps come up with a plan to merge two widely used scanning devices—the PET and the CT—into one

BY LEON JAROFF

INVENTIONS

THE IDEA CAME OUT OF LEFT field. Electrical engineer Ronald Nutt and physicist David Townsend, working at the University of Geneva in Switzerland, had just taken the cover off their newly developed metabolic-imaging machine and were admiring its innards when an oncology surgeon happened by. "You have a lot of space between those detectors," he offered. "You ought to try to put something in there that would be useful."

At the time, eight years ago, PET (positron emission tomography) machines, which can reveal subtle metabolic processes such as tumor growth, and CT (computerized tomography) scanners, which show precise anatomical details, were already in widespread medical use. But doctors, especially cancer surgeons, were often frustrated in their attempts to match the two different scans to determine, for example, the precise location of a tumor in relation to an organ or to the spinal column. There seemed to be no better way than simply "eyeballing" the two separate images.

That is, until Nutt and Townsend had their epiphany in the Alps. Last October the U.S. Food and Drug Administration approved the marketing of a combination PET/CT machine, the first medical-imaging device that simultaneously and clearly reveals both anatomical details and metabolic processes

within the body. By early next year the new scanners will be installed at Manhattan's Memorial Sloan-Kettering Cancer Center, Indiana University, the University of Iowa and other medical facilities.

Others had attempted, with little success, to match the two different images by using computer algorithms as a way to unify data from CT and PET scans made at different times and in different settings. "The problem is that the body is kind of a flimsy structure," says Nutt, co-founder of CTI, the Knoxville, Tenn., imaging company that is gearing up to produce the new scanning combine. "If you lay it on the bed one time for a CT scan and another time for a PET scan, just a small difference in body position will result in all of the organs shifting about a bit, so it's very difficult to do that matching."

After refining their combined PET and CT concept for three years, Nutt and Townsend, who had transferred from the University of Geneva to the University of Pittsburgh, received a three-year, $1.5 million grant from the National Cancer Institute in 1995 that enabled them to complete a prototype machine. Installed at the University of Pittsburgh medical center in 1998,

it has been used successfully to scan some 200 patients.

In many of these cases, says Dr. Carolyn Cidis Meltzer, who with Townsend is a co-director of the University of Pittsburgh PET facility, the use of the PET/CT machine has resulted in decisions to modify or change treatment. In one case a standard CT scan had detected a tumor on the left side of a patient's neck but none elsewhere. "When CTs are read and you look for a spread of tumor to the lymph nodes," Meltzer explains, "all you're able to look at is the size of the lymph node."

If a CT shows that a lymph node is less than one centimeter in size, it is considered to be normal. But on the PET/CT, Meltzer says, "we saw a very small lymph node in the right side of the neck that we thought was involved with the tumor." A biopsy that otherwise would not have been performed confirmed her suspicion.

The Pittsburgh machine has also made a difference in the diagnosis and treatment of cervical and ovarian cancers. Blood tests of some women who had already been successfully treated

for these malignancies began to show markers suggesting that tumors were recurring. CT scans showed nothing amiss, but PET/CT surveys revealed the precise locations of small new tumors in the pelvic area that surgeons were able to remove before they metastasized.

Despite the limitations of a standard CT, it does a superb job of picturing the internal anatomy of the body. "The CT shines a fan beam of X rays though the human body," Nutt explains, "and makes a series of slices. Al-

INVENTORS

ILLUSTRATION FOR TIME BY CHRISTOPH NIEMANN

most what you'd see if you took a knife and cut a person in two." Literally slices of life.

These slices are made possible by the CT's detectors, which gauge the attenuation of the X-ray beam as it passes through the body. The attenuation, in turn, is a measure of the mass that the X rays encounter in their passage.

And that measurement is translated into precise images of the body's internal structure by an algorithm programmed into the CT computer. The newest machines, called spiral CTs, take many slices in rapid succession and can now image the entire torso in seconds, a procedure that once took as long as an hour.

The PET scan operates on an entirely different principle. In one application, a solution of sugar, its molecules tagged with a radioactive chemical isotope (usually fluorine 18) is injected into a patient's veins. Like any sugar, it migrates to metabolically active vital organs and tumors, if any, which use it for energy.

As the radioactive fluorine isotope, now concentrated in the organs and tumors, decays, it gives off positrons, the antimatter counterpart of electrons. And when an ejected positron collides with an electron, which occurs almost simultaneously, both particles are annihilated, their mass instantly converted into gamma rays, which the PET machine detects and turns into an image.

If there is a metabolically active tumor in the region being scanned, says Meltzer, "you can see an area where there has been sugar uptake. But it looks like a blob and it's difficult, especially in some parts of the body, to tell exactly where it is." Dr. Steven Larson, director of the PET program at Manhattan's Sloan-Kettering, has his own description of the blob: "It's a little like lighting a match in the blackness of a vast cavern. We detect the match, but the location is imprecise."

In designing the PET/CT to remedy this imprecision, says Townsend, one of the problems that he and Nutt faced was the engineering of the scanner tunnel into which the patient is rolled. "You don't want a very long tunnel that's frightening to patients," he explains. To further minimize the claustrophobic effects, they increased the diameter of the PET/CT tunnel to 28 in., making it far more spacious than the familiar typical magnetic resonance imaging (MRI) tunnels. "For the patient, it's very comfortable and convenient," says Townsend. "They arrive, they have a single scan, and then we have all the information."

A far greater problem came in writing the code to run PET/CT's computer. "We needed and finally created software to control two different imaging systems from one computer console," says Townsend, "something that hadn't ever been done before."

Now, given the go-ahead by the FDA, CTI will soon be producing an advanced version of the Pittsburgh prototype. Larson, who has ordered a machine for Sloan-Kettering's PET center, predicts that the PET/CT will "improve clinical management of patients and cut the overall time of their imaging in half, from about one hour for a whole body survey to about a half hour."

Even apart, PET and CT scanners are triumphs of technology, devices that have saved countless lives, prolonged others, and often made many exploratory operations unnecessary. Yet each has limitations that can lead to uncertainties in diagnosis. By successfully combining the two technologies, Ronald Nutt and David Townsend have eliminated those uncertainties and provided medicine with a powerful new diagnostic tool. ∎

COMING UP NEXT

NANOSURGERY

A diagnosis of pancreatic cancer would be devastating to any of us, bringing with it the horrors of debilitating chemotherapy and a slim chance of surviving the next five years. Fifteen years from now, however, you might not even bat an eye at the news. Your doctor will simply hand you a capsule packed with millions of sensors, each programmed to seek out and kill the cancer cells in your body. A few weeks and a dozen doses later, your tumors will be gone—destroyed while you were going about your daily routine.

This isn't science fiction. The National Cancer Institute and NASA plan to spend $12 million a year for the next three years to develop nanosensors—devices less than one-thousandth the diameter of a human hair—that will scan the body for the molecular signatures of cancer—the aberrant proteins found on malignant cells, for instance—and map the locations and shapes of tumors. If engineered to carry drugs or genes, the sensors could treat cancers one cell at a time, attacking malignant cells but leaving healthy ones unharmed. The result: an end to the pharmaceutical carpet-bombing we call chemotherapy, not to mention its attendant miseries.

And that's not all. One day, autonomous "nanobots" far smaller than motes of dust will patrol the body, repairing aging organs and fixing genetic damage before it can turn into disease. But nanomedicine is still in its infancy, cautions Carol Dahl, co-director of the NCI/NASA collaboration. "Most of the work we're seeing out there right now asks, What are the widgets we can build? Next, the question will be, How can we apply them to solve specific problems?" Mihail Roco, adviser to the National Science Foundation's $150 million nanotechnology initiative, believes we will have an answer soon enough. He predicts that the rudiments of nanotechnology will aid the manufacture and design of up to half of all drugs by the end of this decade.   —By Unmesh Kher

Patients arrive, they have a **single scan,** and the doctors have all the information

EXHIBIT 8

GEMINI TF

The First Commercial Time-of-Flight PET System

2006 IEEE Medical Imaging Conference

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# New PET/CT Design Challenges
Image Quality & Applications

- *Significant* improvement in image quality
  - How can you improve my diagnostic confidence? What is the smallest lesion I can see? How consistent is image quality?

- Support of *all* clinical applications
  - Can I use the scanner for Oncology, Cardiology and Neurology applications?
  - Can I research new Molecular Imaging tracers?

- Is the technology *easy to use*?
  - Will the system be reliable, stable and user friendly?
  - Does the technology support *clinical workflow* requirements?

Small lesion detectability

2
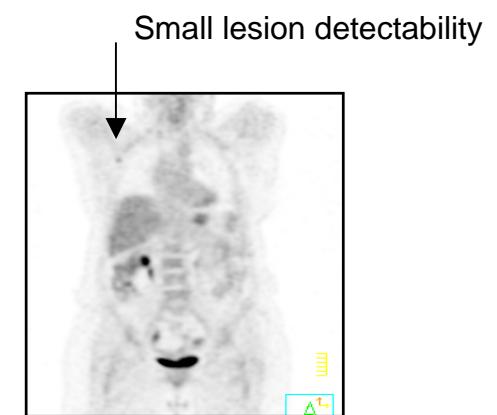
PHILIPS

New PET/CT Design Challenges

Inconsistent image quality between patients of different sizes
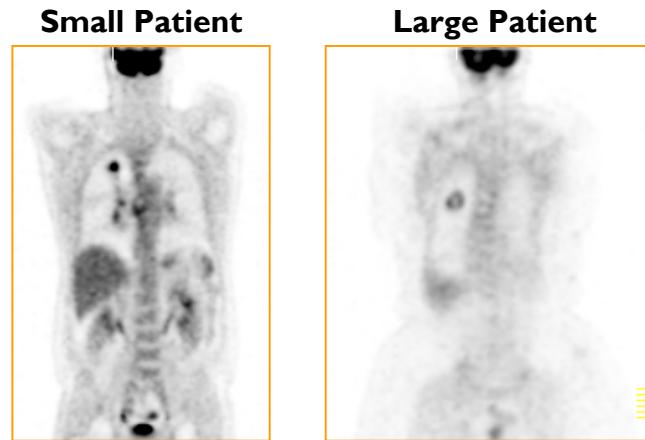
This is a documented issue with all PET systems:

• For an equivalent data signal to noise ratio, a 120 kg person would have to be scanned *2.3 times longer* than a 60 kg person

• *5 min/bed position* scans are sufficient for optimal lesion detection with LSO PET/CT in obese patients

---

Optimizing Injected Dose in Clinical PET by Accurately Modeling the Counting-Rate Response Functions Specific to Individual Patient Scans. Charles C. Watson, PhD et al Siemens Medical Solutions Molecular Imaging, Knoxville, Tennessee, JNM Vol. 46 No. 11 1825-1834, 2005

Optimizing Imaging Protocols for Overweight and Obese Patients: A Lutetium Orthosilicate PET/CT Study, Benjamin S. Halpern, et al, UCLA David Geffen School of Medicine, Los Angeles, California, JNM Vol. 46 No. 4 603-607, 2005

PHILIPS

PET/CT Design Challenges

Cardiology & Molecular Imaging

Cardiology*

- *Low statistics* - EKG gated imaging
- *Low statistics* - Kinetic modeling (N-13 ammonia)
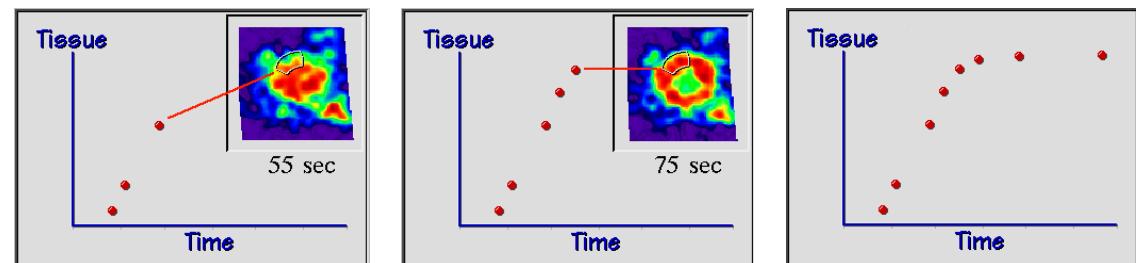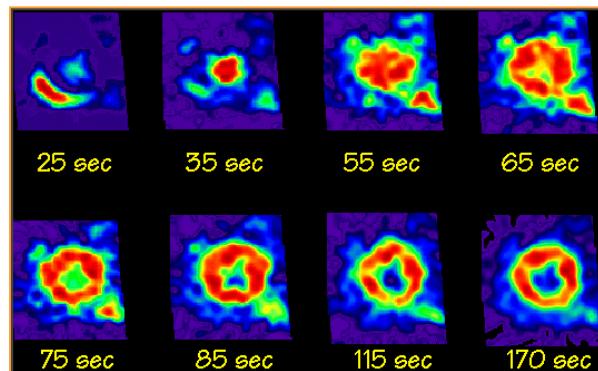
* - Crump Institute for Molecular Imaging UCLA School of Medicine

Molecular Imaging Applications

- *Low statistics* – dynamic imaging
- *Low statistics* – specific isotopes, low dose isotopes
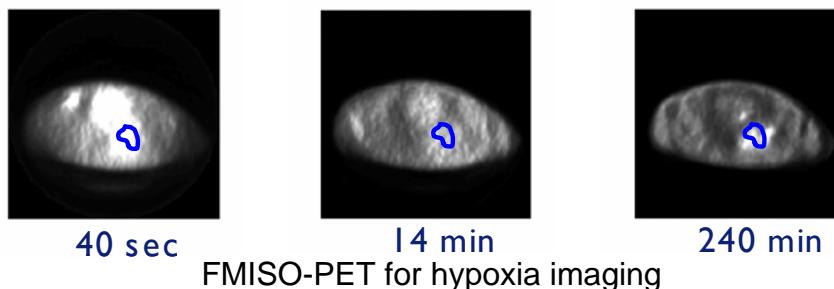
FMISO-PET for hypoxia imaging

4
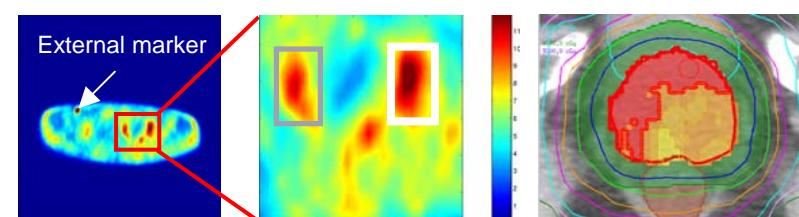
PHILIPS

Time-of-Flight
Basic Concept
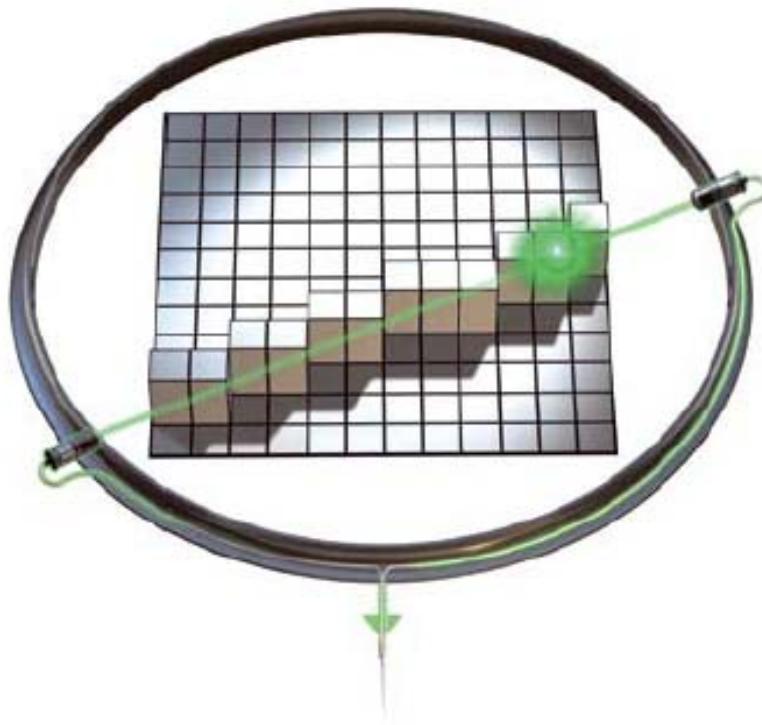
**Coincidence and
backprojection**
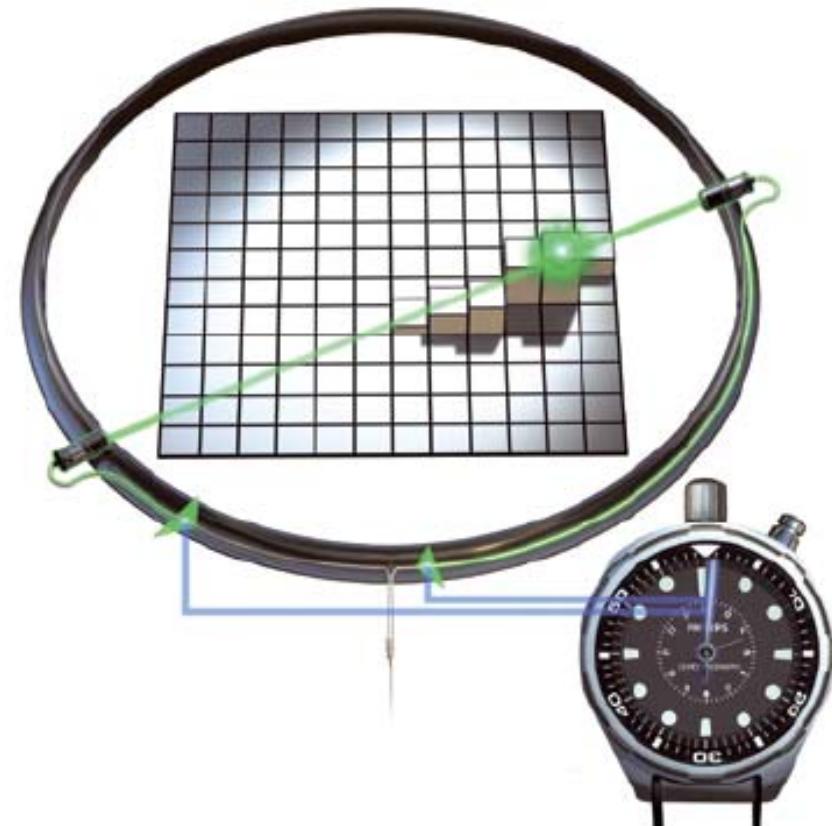
**Timing within
coincidence window**

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Time-of-Flight vs. Conventional PET

Better information sent to reconstruction
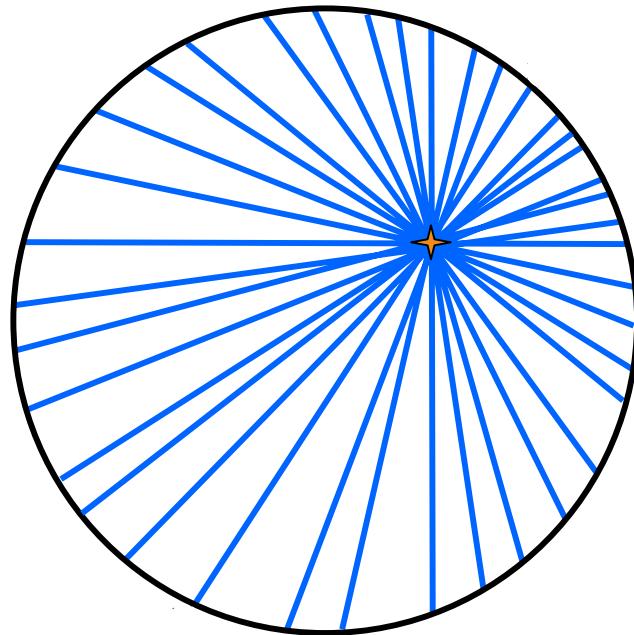
**Conventional PET
Image Formation**
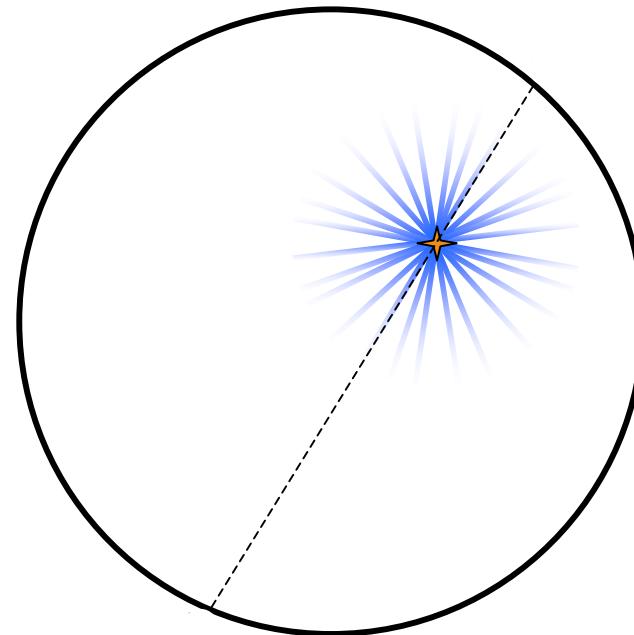
**Time-of-Flight
Image Formation**

More precise localization of annihilation event improves image quality

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Time-of-Flight

Effect of System Timing Resolution
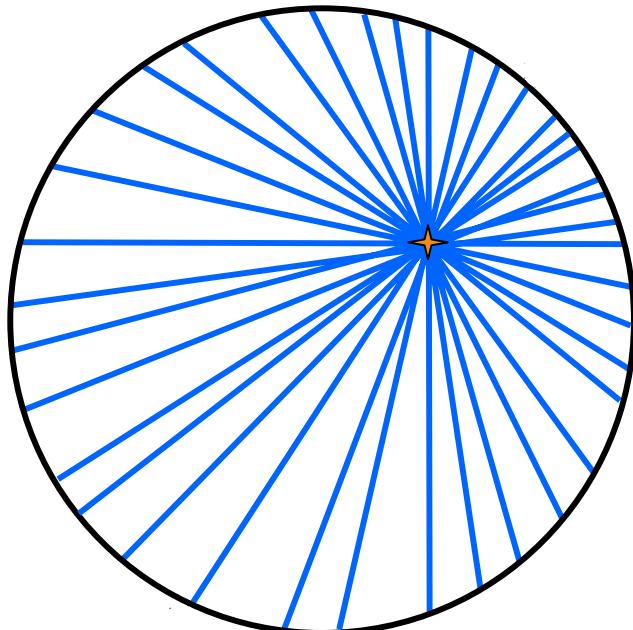
**Conventional PET
Image Formation**
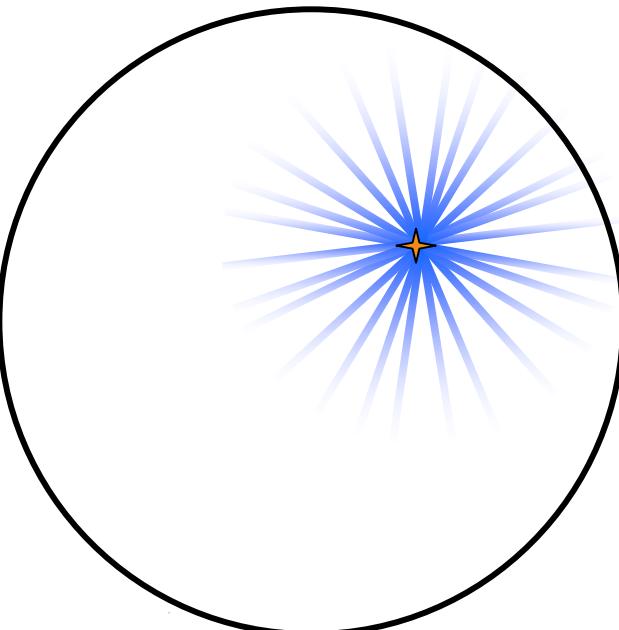
**1 ns ToF
Image Formation**
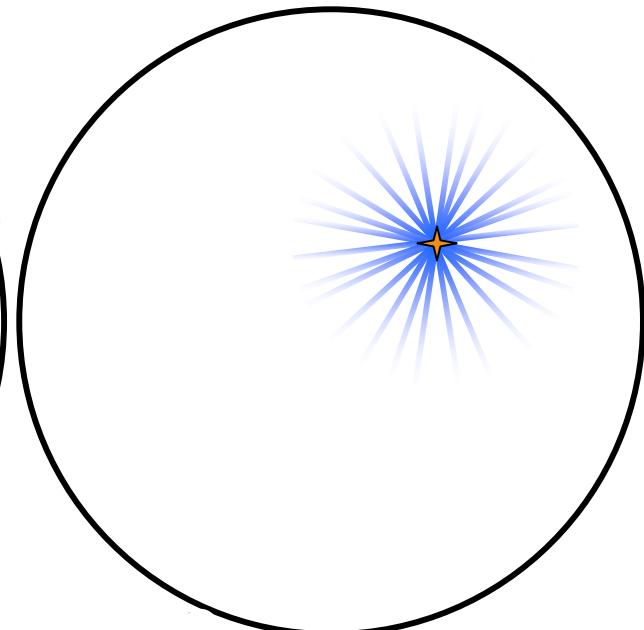
**TruFlight (~650 ps)
Image
Formation**

System timing resolution defines performance benefit of time-of-flight

Time-of-Flight
TruFlight Imaging Benefits

Data courtesy of J Karp, University of Pennsylvania

3D RAMLA   Line of Response   Time-of-Flight
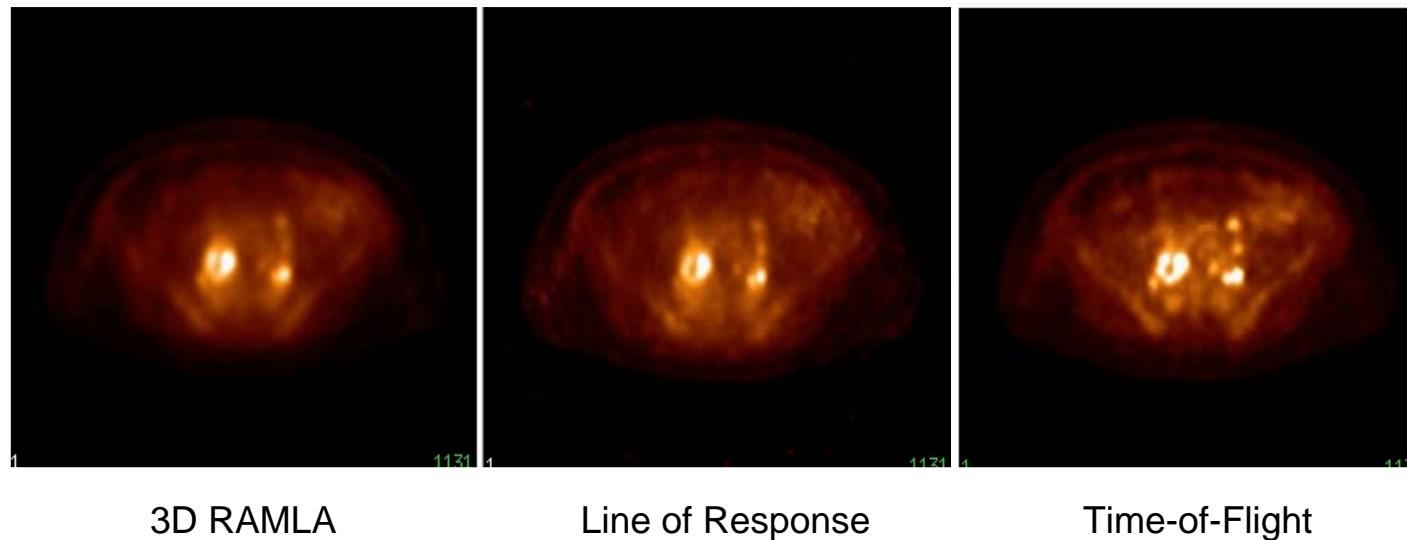
Time-of-flight improves image quality

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Quantifying Image Quality Benefits

Sensitivity Gain[1]

Sensitivity Gain =
    Object (Patient) Size / ToF Positioning Accuracy

ToF Positioning Accuracy =
    c x Timing Resolution / 2
c = Speed of Light

Effective NECR = NECR_0 x Sensitivity Gain
NECR_0 = Conventional (NEMA) NECR
Effective NECR = Time of Flight NECR

TruFlight
    – *sensitivity gain ~ 2x - 4x*
    – *positioning accuracy <10 cm*
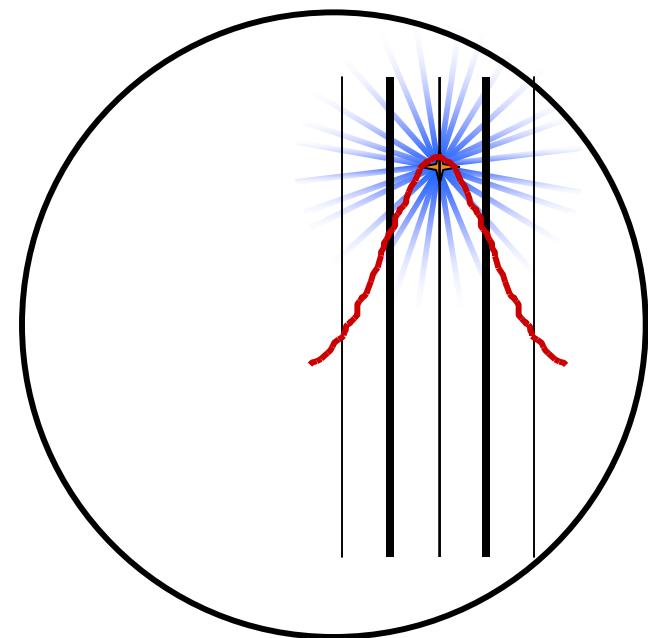
TruFlight
**Timing Resolution
~650 ps**

[1] Budinger TF. Time-of-Flight Positron Emission Tomography: Status Relative to Conventional PET.

J Nucl Med 24(1):73-78, **1983**.

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Imaging Challenge
Patient Body Size*

Histogram of the patient body diameter for 65 randomly selected patients
Average patient diameter = 27 cm
Large patient diameter =   35 cm
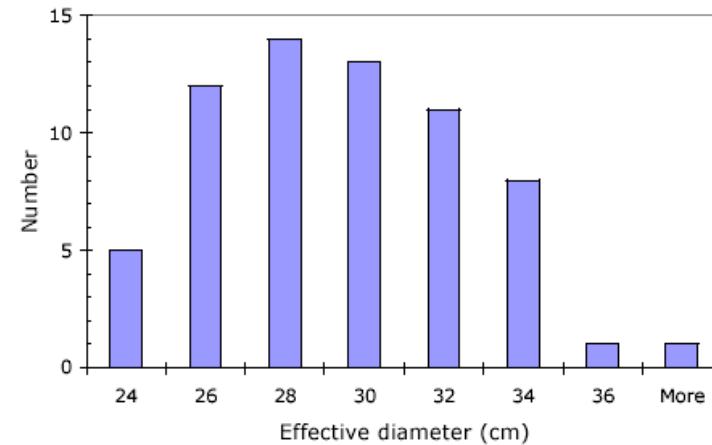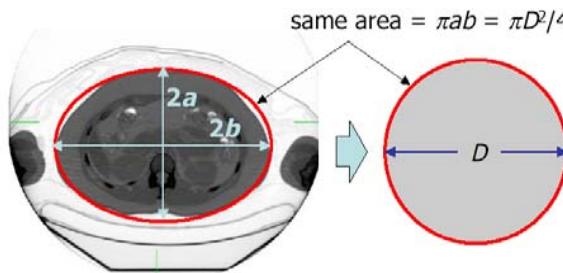
* A Quantitative Approach to a Weight-Based Scanning Protocol for PET Oncology Imaging. Paul Kinahan, Phillip Cheng, Adam Alessio, Tom Lewellen, University of Washington, Seattle. Presented at MIC conference 2005. Data used with authors permission.

Dutch clinics under strain from obese patients

Wed Jan 18, 2006 5:11 PM GMT.

AMSTERDAM (Reuters) - Dutch hospital beds and operating tables could buckle under the strain of obese patients, doctors have complained, adding some patients barely fit into scanning machines.

TruFlight Technology

Benefits increase with the size of the patient

Sensitivity Gain = Object (Patient) Size / ToF Positioning Accuracy

Small Patient

Sensitivity Gain = 2.5X

Average Patient
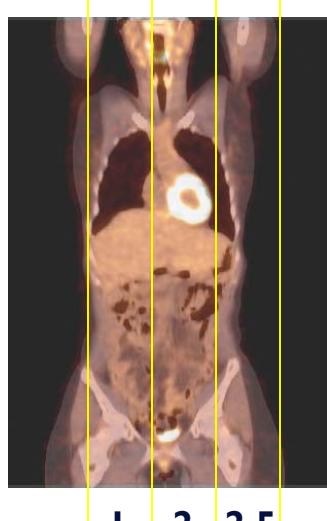
Sensitivity Gain > 3 X
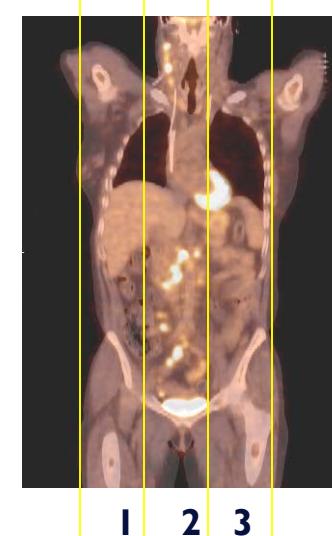
Large Patient

Sensitivity Gain = 4.0 X

- Time of flight reduces noise resulting in higher image quality, shorter scans or lower dose
- Image quality improvement is higher in large patients resulting in consistent image quality across patients

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GEMINI TF

Technology

PHILIPS

Philips PET
TruFlight
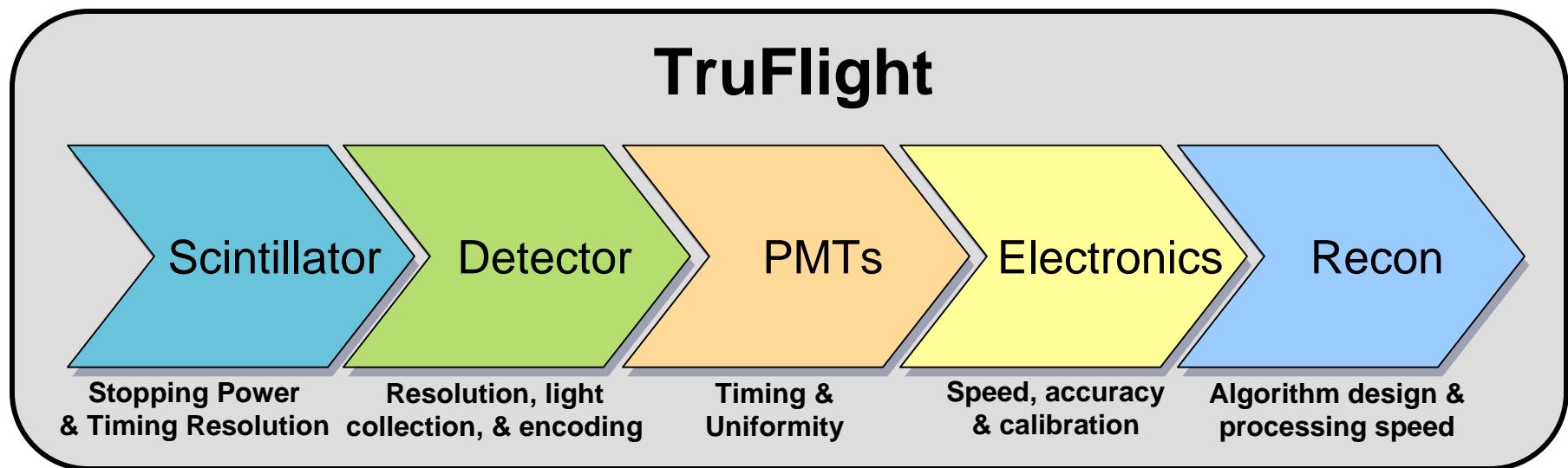
All aspects of system design must be optimized for Time-of-Flight Imaging

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TruFlight

Scintillator – Stopping Power & Timing Resolution

Scintillator
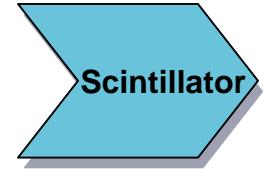
Property	LSO	LYSO	GSO	BGO	LuAP	LaBr$_3$
Density Effective Z Attenuation length	7.4 66 1.15	7.1 (10% Y) 64 1.2	6.7 57 1.4	7.1 75 1.04	8.3 66 1.04	5.3 47 2.1
Energy Resolution	~11%	~10%	~10%	>13%	7-9%	3%
Light Yield	1.0	1.2	<0.5	<0.2	~0.5	2.0
Decay Time	~40 ns	~40 ns	60 ns	300 ns	17 ns	35 ns
Timing Resolution (two crystals in coincidence)	~450 ps	<450 ps	Not optimal performance for time of flight	Not suitable for ToF	500ps	<400ps

LYSO selected because of **timing resolution**, stopping power & availability

The rest of the system design must maintain as much of this intrinsic timing resolution as possible!

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TruFlight

Detector – Resolution, light collection, & encoding
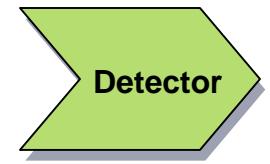
Detector

1. With ToF, small crystal size (4x4x22mm) AND exceptional sensitivity

2. Preserve intrinsic energy resolution with PIXELAR detector design
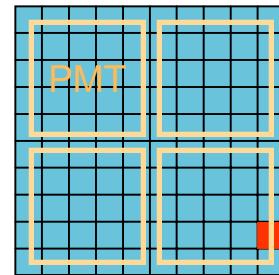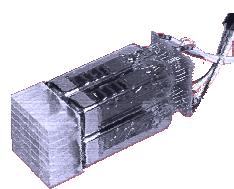
Conventional Block Detector
- Optically isolated from surrounding blocks
- 4 PMTs used to localize
- Light collection dropoff at edges of blocks
- Light collection variability with position
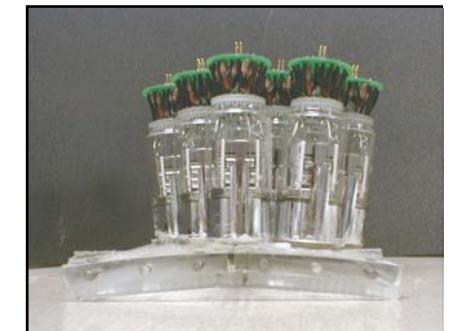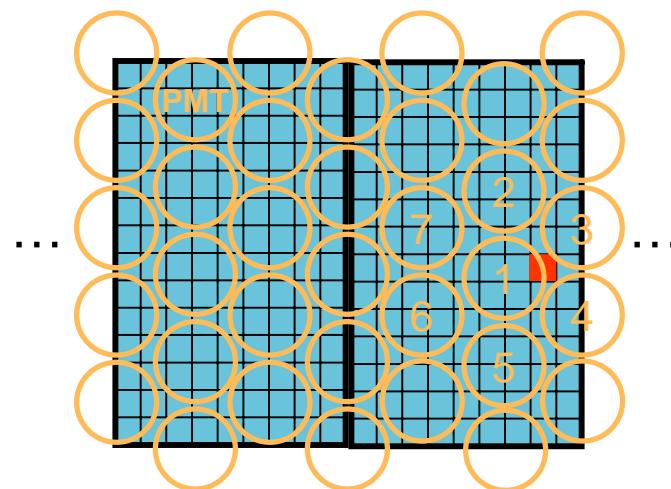
Philips PIXELAR Detector
- Panels connected optically via continuous lightguide
- 5-7 PMTs used to localize, better identification
- Light collection dropoff only at edge of FOV
- Small light collection variability

Results: Energy Resolution of 12% and 30% Scatter Fraction

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TruFlight
PMTs – Timing and Uniformity
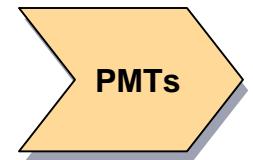
PMTs

- PMT choice critical to timing resolution & stability
- Conventional PMTs are not suitable for ToF imaging
  - flat cathode delivers non-uniform timing response
  - unacceptable loss in timing resolution
- Uniformity of timing response across tube (= among crystals) is critical to preserve system timing resolution, requires curved cathode


Conventional (flat) PMT

TruFlight PMT (curved) PMT

16
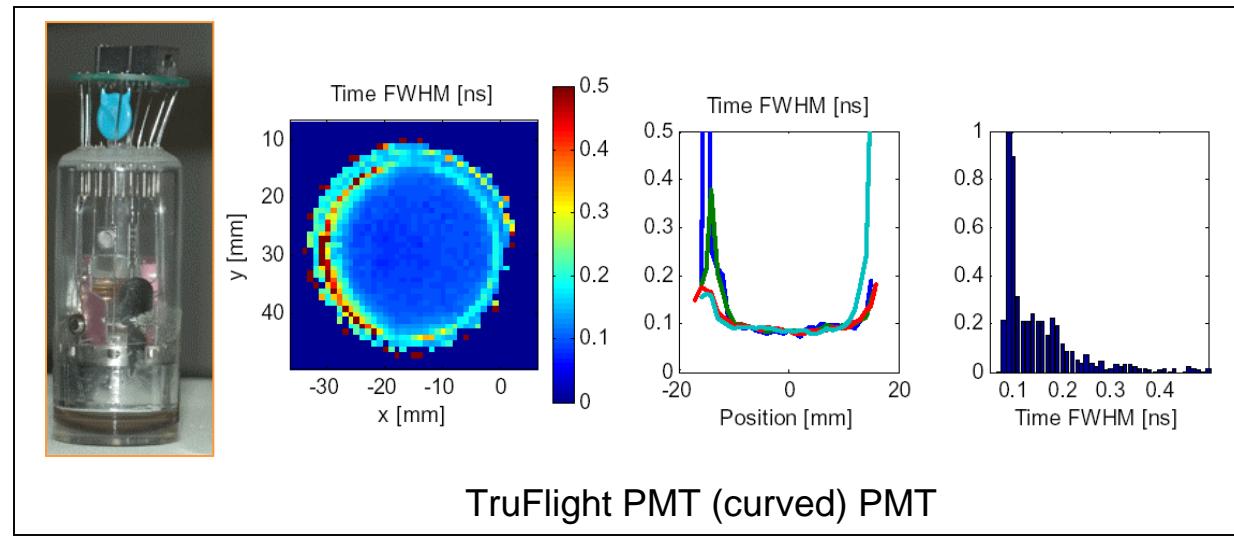
PHILIPS

TruFlight

Electronics – Speed & Accuracy
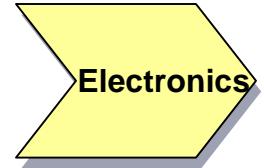
Electronics

Designed for Timing Accuracy
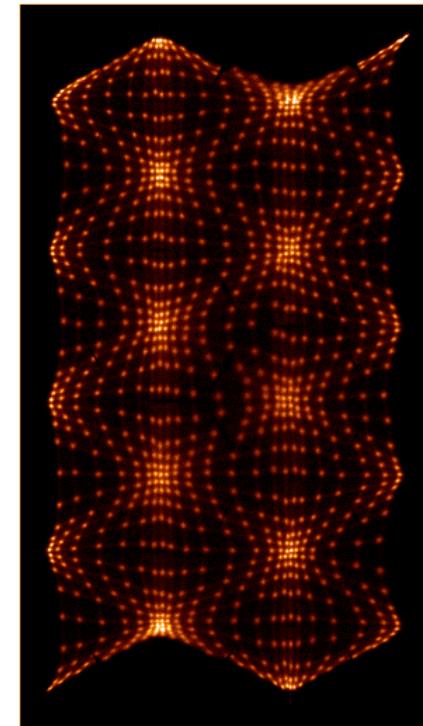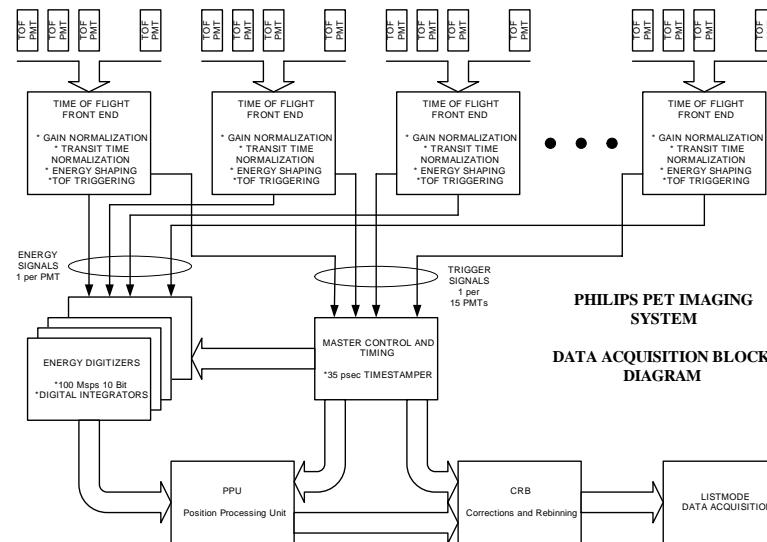
- 25 psec time stamp for accurate data sampling

- ToF Timing Resolution – 650 psec
    - Crystal   450 psec
    - PMTs   100 psec
    - Other   100 psec – electronics design plays a key role in preserving the timing resolution

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TruFlight

Electronics – Calibration

Electronics
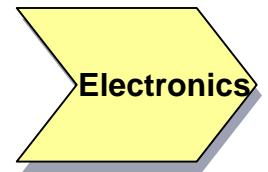
- Historical (1980s) research systems
  - timing stability measured in minutes
  - recalibration measured in hours
- Clinical requirement: stable time response for <u>days</u> & easy and fast recalibration
- GEMINI TF designed for ~5 minute (daily) automated timing calibration (standard Na-22 source) and consistent performance

Timing Resolution (FWHM) vs. Time

Graph depicts system timing resolution measured daily on a system in clinical usage at the Hospital of the University of Pennsylvania

Dec-05   Feb-06

18
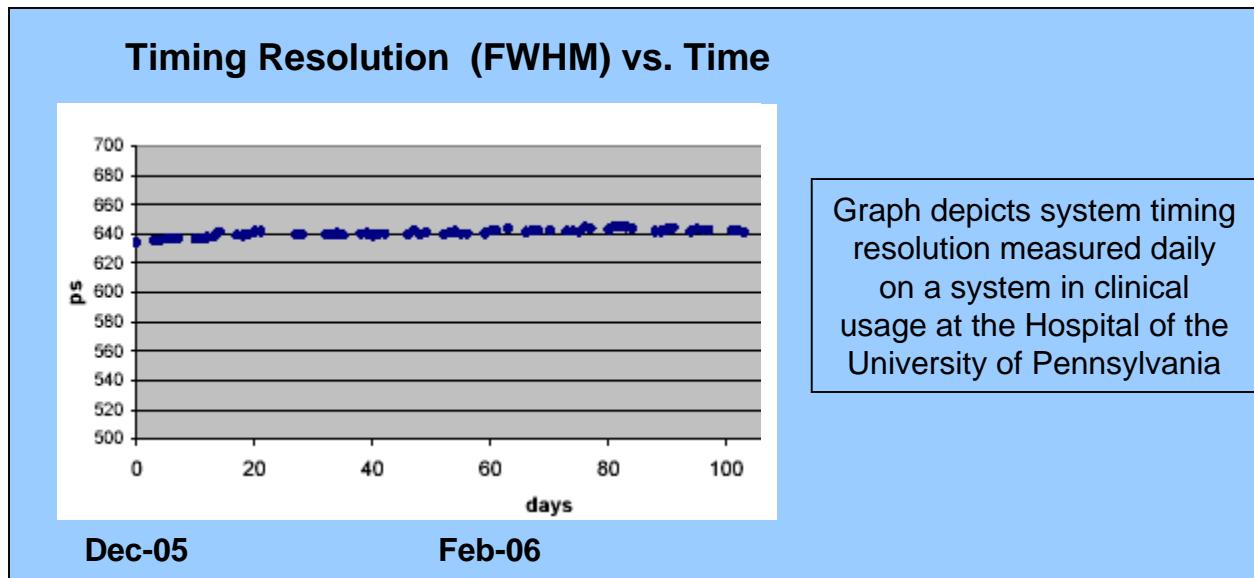
PHILIPS

TruFlight

Reconstruction – Algorithm Design
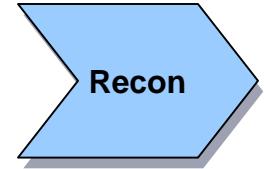
Recon

- Technical challenge: acceptable reconstruction times with an extremely large data set (~10x compared to LOR)

- Enhancements in available computing power are one of the key enablers of clinically useful ToF imaging

- New TruFlight Reconstruction Algorithm
  - Event-by-event reconstruction requires list mode acquisition & processing
  - Based on RAMLA / Blob & LOR
  - Now incorporates relative timing information

$$\hat{f}_i^{k+1,OSEM} = \hat{f}_i^k \left\{ (1-\lambda) + \frac{\lambda}{S_i} \sum_{j=0}^{J-1} H_{ji}^{objRayWt} H_{ji}^{TOF} \frac{1/(\eta_j^{xtaleff} \eta_j^{decay} \eta_j^{deadtime} \eta_j^{det\,geom})}{\sum_{n=0}^{N-1} H_{jn}^{objRayWt} H_{jn}^{TOF} \hat{f}_n^k + \frac{r_j + sc_j(\hat{f}^k, \mu)}{\eta_j^{det\,geom} \eta_j^{atten}}} \right\}$$

$$\text{where} \quad s_i = \sum_{all\,possible\,j} \eta_j^{atten} H_{ji}^{objRayWt} H_{ji}^{TOF}$$

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TruFlight

Reconstruction – Processing Speed
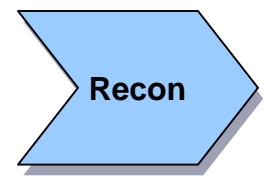
Recon

TruFlight reconstruction architecture converts a very large task (~10x compared LOR recon) into multiple smaller tasks to then distributes it to more computers (CIRS)
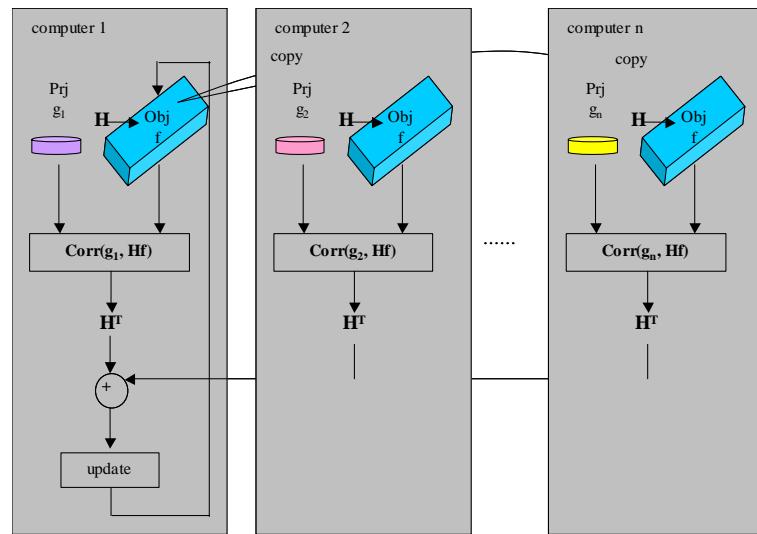
**Multi-processor dedicated reconstruction Computer**
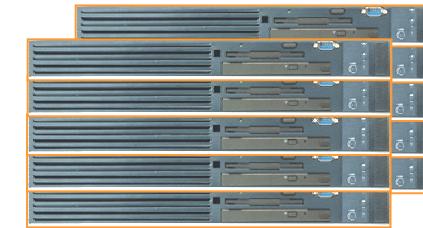
Distribution of the projection data among multiple processors results in a clinically practical reconstruction time

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TruFlight
Strategic Design over Time

TruFlight

Scintillator	Detector	PMTs	Electronics	Recon
Stopping Power & Timing Resolution	Resolution, light collection, & encoding	Timing & Uniformity	Speed, accuracy & calibration	Algorithm design & processing speed
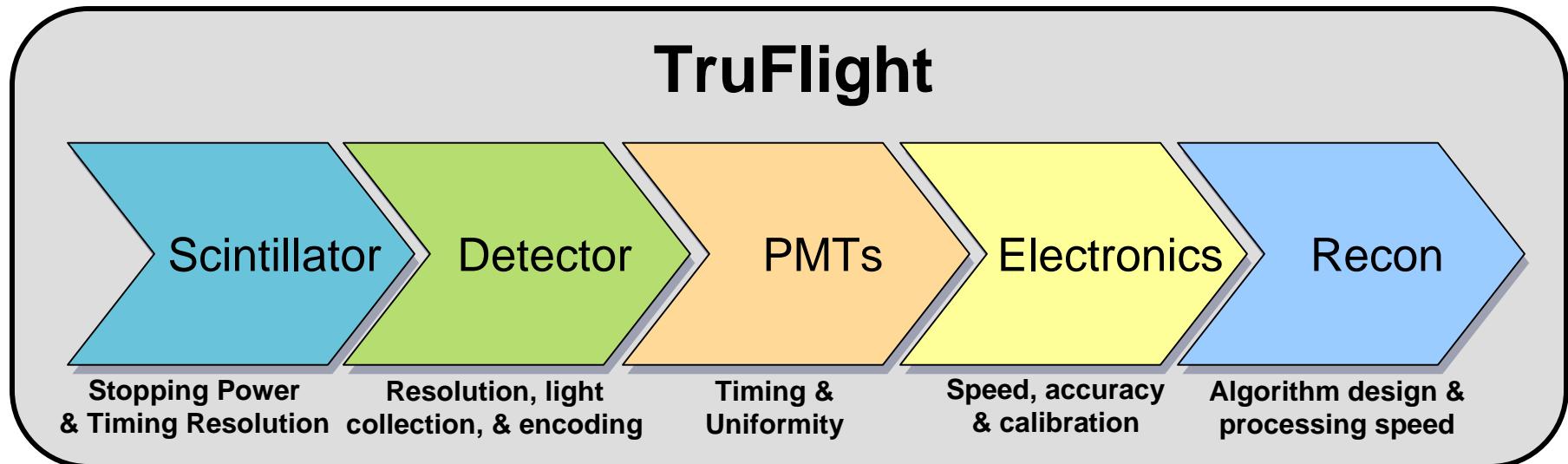
- ToF imaging cannot be simply "added" to a conventional system
- Philips has been developing the building blocks for many years

| Key Time-of-Flight Enabler	Philips Product
Pixelar detector design	Allegro
3D RAMLA Reconstruction	Allegro
List mode acquisition	GEMINI
LOR ("crystal space" processing)	GEMINI GXL
CIRS distributed processing architecture	GEMINI GXL
Time-stamping electronics architecture	GEMINI GXL

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GEMINI TF

Clinical Results

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78 kg
171 lbs
12 mCi
<15 min acquisition

GEMINI TF Performance
Image Quality
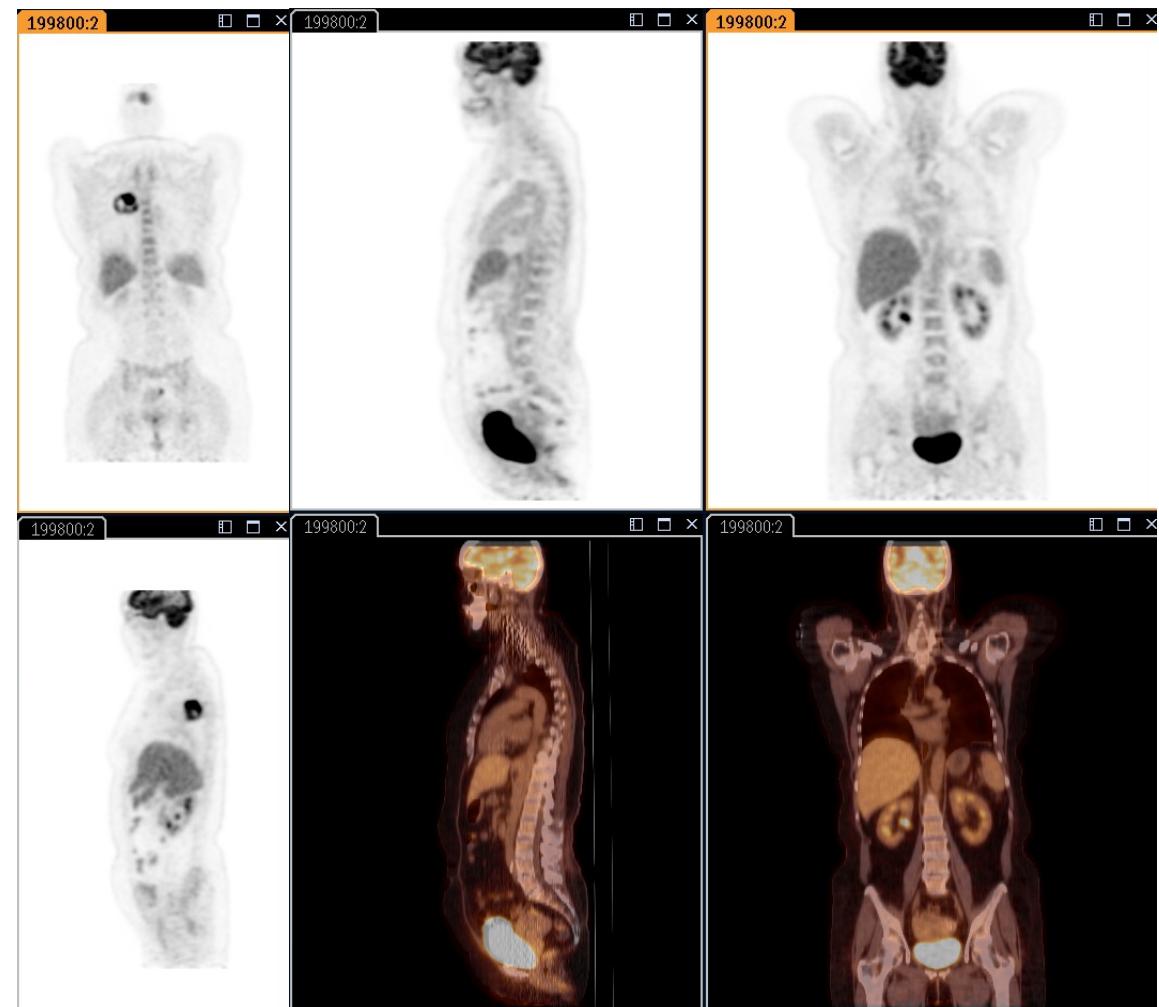
Images courtesy of University Hospitals of Cleveland

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GEMINI TF Performance
## *Image Quality*

8.5 mCi
19 min acquisition

Images courtesy of Montefiore Medical Center

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GEMINI TF Performance

Image Quality

Arms Down
9.2 mCi
19 min acquisition

Images courtesy of Montefiore Medical Center

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GEMINI TF Performance
Image Quality

103 kg
227 lbs
12.3 mCi
<15 min acquisition

Images courtesy of University Hospitals of Cleveland

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GEMINI TF Performance

Image Quality

141 kg
310 lbs
10.5 mCi
19 min acquisition

6 dm

Images courtesy of Montefiore Medical Center

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GEMINI TF Performance

Image Quality

Images courtesy of University Hospitals of Cleveland

GEMINI TF Performance
Image Quality

Aorta

68 kg
150 lbs
10.3 mCi
<15 min acquisition

Images courtesy of University Hospitals of Cleveland

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GEMINI TF Performance

Neurology Image Quality
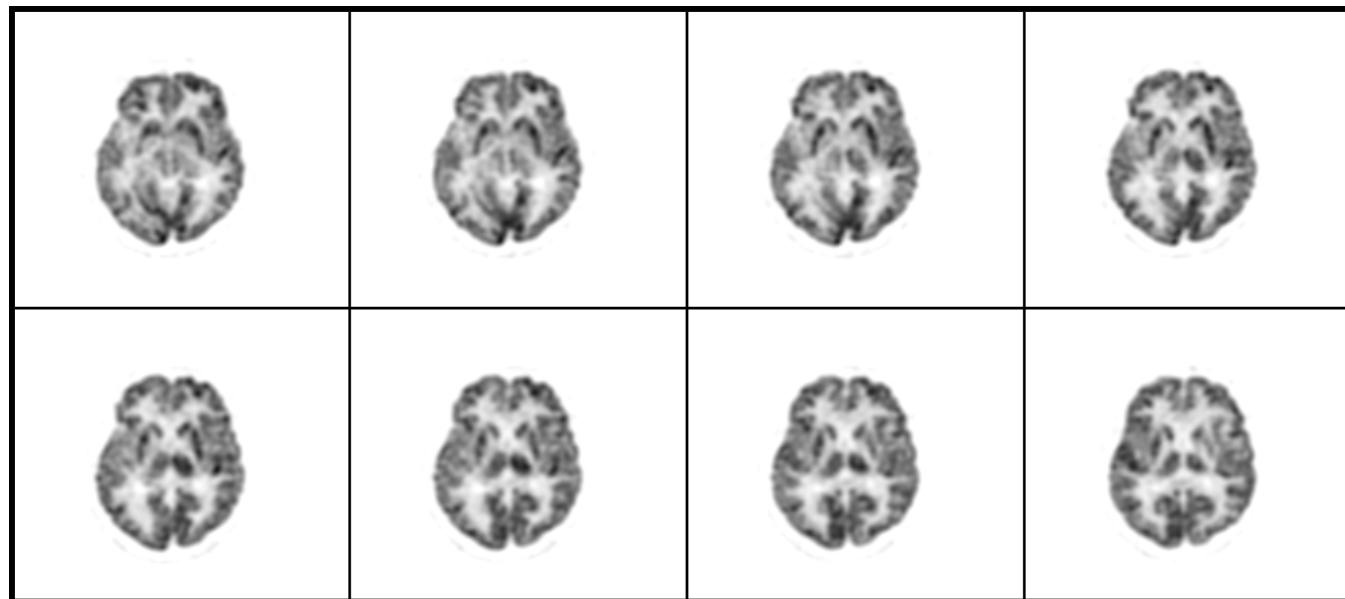
10 mCi
10 min PET Acquisition

Images courtesy of University Hospitals of Cleveland

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GEMINI TF Performance
Fast Acquisition (<10 Minute PET Acquisition)

74 kg
163 lbs
9.5 mCi

Images courtesy of Montefiore Medical Center

31
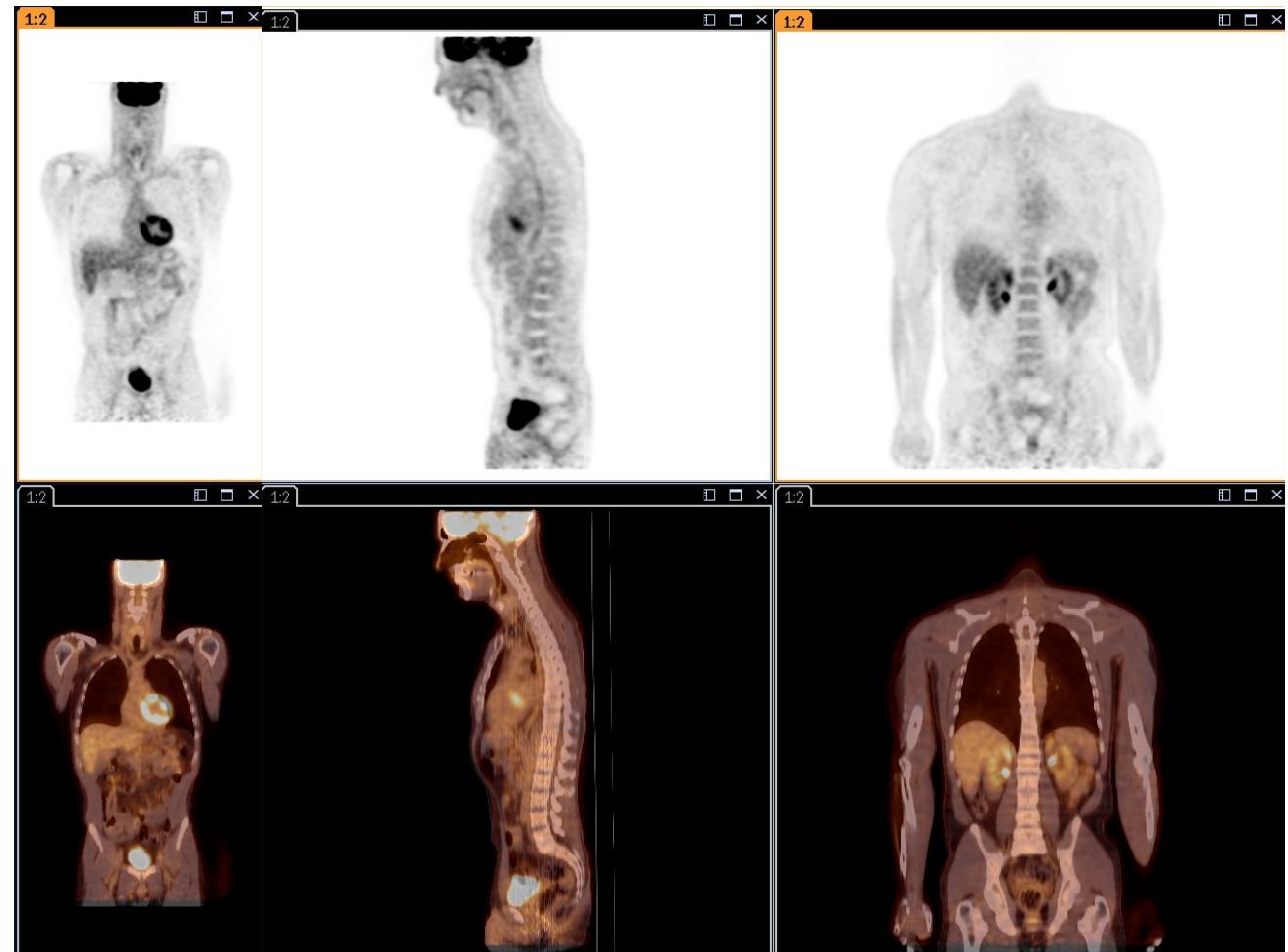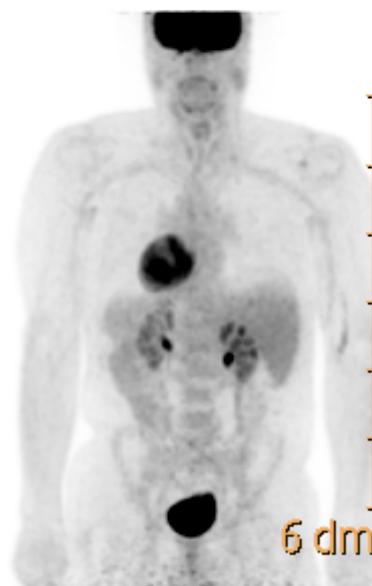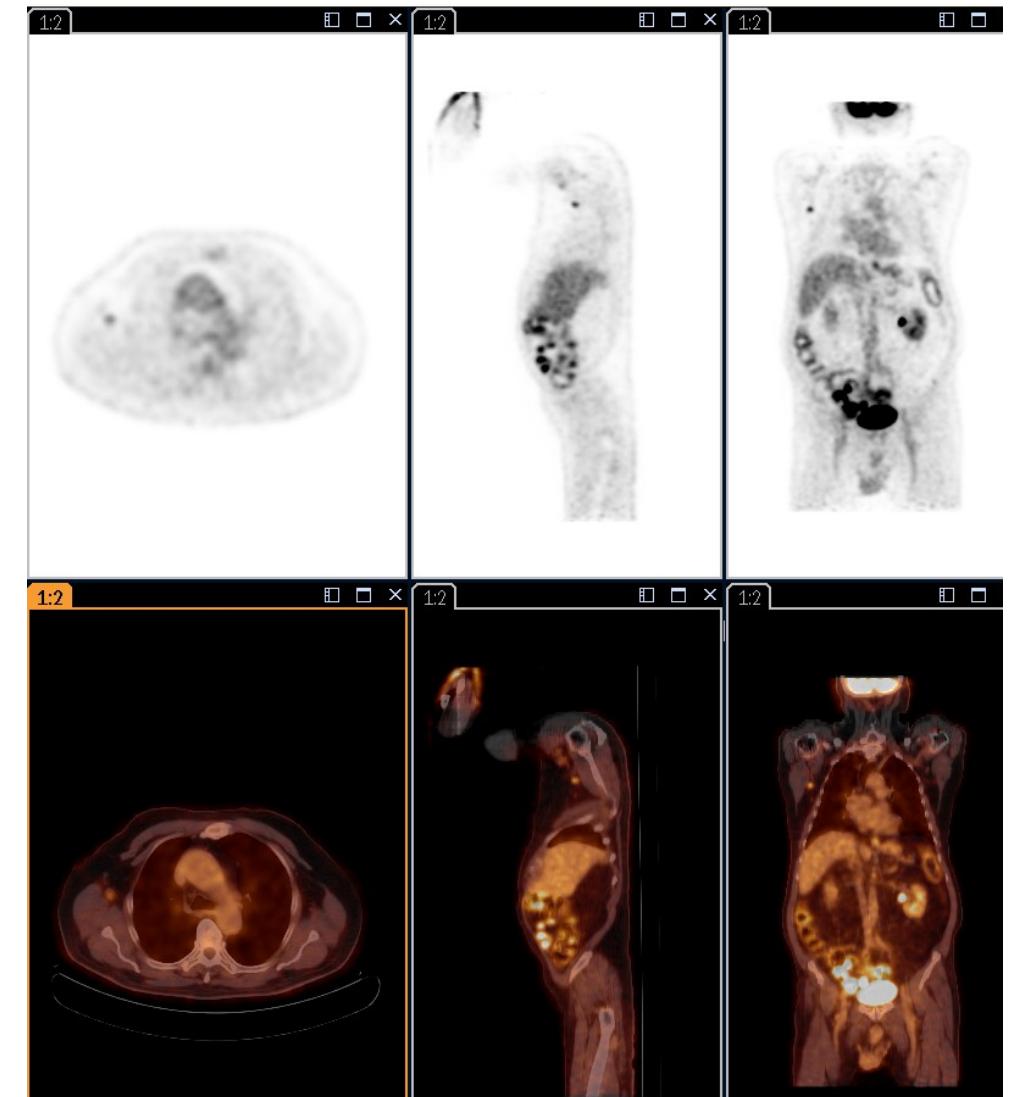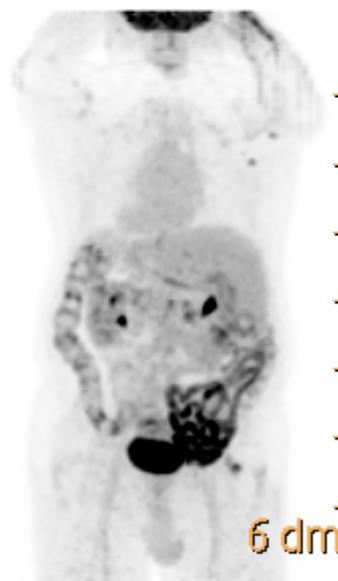
Images courtesy of Montefiore Medical Center

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GEMINI TF
Oncology

- Visualize smaller lesions through improved image accuracy and higher sensitivity.
- Consistent image quality in large patients.

Small Patient   Large Patient

Small Patient   Large Patient

Conventional PET

GEMINI TF

TruFlight < 10 min whole body PET for every body

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GEMINI TF
TruFlight Technology

Perfect for every body.

Unquestionably unequivocal

- Extracting the true benefits of time-of-flight technology

    - Improved image quality, lesion detectability and patient throughput

- Creating the new benchmark in consistent image quality

- Opening the pathway to molecular imaging applications

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Perfect for every body.

GEMINI TF PET/CT.

The new benchmark in speed, comfort, clarity and flexibility.

EXHIBIT 9

OCT 7 - 2005   *K052640*

510(k) SUMMARY OF SAFETY AND EFFECTIVENESS

General Information

A.   *Submitter/ Contact Person*:

Philips Medical Systems (Cleveland), Inc.   Melinda Novatny
595 Miner Rd.   Tel: (440) 483-4255
Cleveland, OH 44143   Fax: (440) 483-7339

B.   *Device Trade Name*: Gemini Raptor

    Common Name: Positron Emission Tomography
                          Computed Tomography X-Ray

    Classification Name: System, Emission Computed Tomography, (892.1200)
                          System, Computed Tomography X-Ray, (892.1750)

    Device Class: 21CFR 892.1200, Class II
                          21 CFR 892.1750, Class II

    Product Code: 90 KPS and 90 JAK

    Classification Panel: Radiology

C.   *Date prepared*:   September 15, 2005

D.   *Predicate Device*:   Gemini GXL System   (K051170)

E.   *Performance Standards:*
   • 21 CFR 1020.30 - 1020.33 Performance Standards for Ionizing Radiation
     Emitting Products, Computed Tomography Equipment (Applicable Sections)
   • NEMA NU-2

F.   *Intended Use*:

The device is a diagnostic imaging system for fixed or mobile installations that combines Positron Emission Tomography (PET) and X-ray Computed Tomography (CT) systems. The CT subsystem produces cross-sectional images of the body by computer reconstruction of x-ray transmission data. The PET subsystem produces images of the distribution of PET radiopharmaceuticals in the patient body (specific radiopharmaceuticals are used for whole body, brain, heart and other organ imaging). Attenuation correction is accomplished by CTAC. The device also provides for list mode, dynamic, and gated acquisitions.

Image processing and display workstations provide software applications to process, analyze, display, quantify and interpret medical images/data. The PET and CT images may be registered and displayed in a "fused" (overlaid in the same spatial orientation) format to provide combined metabolic and anatomical data at different angles. Trained professionals use the images in:

Section X.-1

o The evaluation, detection and diagnosis of lesions, disease and organ function such as but not limited to cancer, cardiovascular disease, and neurological disorders.

o The detection, localization, and staging of tumors and diagnosing cancer patients.

o Treatment planning and interventional radiology procedures.

The device includes software that provides a quantified analysis of with regional cerebral activity from PET images.

Cardiac imaging software provides functionality for the quantification of cardiology images and datasets including but not limited to myocardial perfusion for the display of wall motion and quantification of left-ventricular function parameters from gated myocardial perfusion studies and for the 3D alignment of coronary artery images from CT coronary angiography onto the myocardium.

Both subsystems (PET and CT) can also be operated independently as fully functional, diagnostic imaging systems including application of the CT scanner as a radiation therapy simulation scanner.

G.   *Device Description/ Comparison with Predicate Device*:

The device is a hybrid diagnostic imaging system that combines Positron Emission Tomography (PET) and X-ray Computed Tomography (CT) scanners that can be utilized in fixed installations or mobile environments. The device is comprised of the following system components/subsystems: Positron Emission Tomography (PET), X-ray Computed Tomography (CT), a patient table, gantry separation unit, and the acquisition and processing workstations.

H.   *System Performance Test/ Summary of Studies*:

To minimize electrical, mechanical and radiation hazards, Philips Medical System adheres to recognized and established industry practice. Radiation safety is assured by compliance and certification to the performance standards for ionizing radiation emitting product, 21CFR 1020.30 and 21CFR 1020.33. The radiation safety product report will be filed in accordance with 21CFR 1002.10 with the Center for Device and Radiological Health. Electrical and mechanical safety is assured by adherence and certification to the applicable standards in the IEC 60601-1 series. The device performance was measured in accordance with the NEMA-NU2 standard.

I.   *Comparison to Predicate Devices:*

The basic differences in the system include the following:

• Change from GSO to LYSO crystals
• Modifications to Reconstruction

In conclusion, the device is substantially equivalent to the predicate devices based upon similar intended use, technological comparison, and system performance.

DEPARTMENT OF HEALTH & HUMAN SERVICES   Public Health Service

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OCT 7 - 2005

Food and Drug Administration
9200 Corporate Boulevard
Rockville MD 20850

Philips Medical Systems (Cleveland), Inc.   Re: K052640
% Ms. Elizabeth Drew   Trade/Device Name: GEMINI Raptor
Project Engineer, Medical Device Services   Regulation Number: 21 CFR 892.1200
Underwriters Laboratories, Inc.   Regulation Name: Emission computed tomography system
1655 Scott Boulevard   Regulation Number: 21 CFR 892.1750
SANTA CLARA CA 95050-4169   Regulation Name: Computed tomography
                                                               x-ray system
                                              Regulatory Class: II
                                              Product Code: KPS and JAK
                                              Dated: September 21, 2005
                                              Received: September 26, 2005

Dear Ms. Drew:

We have reviewed your Section 510(k) premarket notification of intent to market the device referenced
above and have determined the device is substantially equivalent (for the indications for use stated in
the enclosure) to legally marketed predicate devices marketed in interstate commerce prior to
May 28, 1976, the enactment date of the Medical Device Amendments, or to devices that have been
reclassified in accordance with the provisions of the Federal Food, Drug, and Cosmetic Act (Act) that
do not require approval of a premarket approval application (PMA). You may, therefore, market the
device, subject to the general controls provisions of the Act. The general controls provisions of the Act
include requirements for annual registration, listing of devices, good manufacturing practice, labeling,
and prohibitions against misbranding and adulteration.

If your device is classified (see above) into either class II (Special Controls) or class III (Premarket
Approval), it may be subject to such additional controls. Existing major regulations affecting your
device can be found in the Code of Federal Regulations, Title 21, Parts 800 to 898. In addition, FDA
may publish further announcements concerning your device in the Federal Register.

Please be advised that FDA's issuance of a substantial equivalence determination does not mean that
FDA has made a determination that your device complies with other requirements of the Act or any
Federal statutes and regulations administered by other Federal agencies. You must comply with all the
Act's requirements, including, but not limited to registration and listing (21 CFR Part 807); labeling
(21 CFR Part 801); good manufacturing practice requirements as set forth in the quality systems (QS)
regulation (21 CFR Part 820); and if applicable, the electronic product radiation control provisions
(Sections 531-542 of the Act); 21 CFR 1000-1050.

This letter will allow you to begin marketing your device as described in your Section 510(k) premarket notification. The FDA finding of substantial equivalence of your device to a legally marketed predicate device results in a classification for your device and thus, permits your device to proceed to the market.

If you desire specific advice for your device on our labeling regulation (21 CFR Part 801), please contact the Office of Compliance at one of the following numbers, based on the regulation number at the top of this letter:

21 CFR 876.xxxx	(Gastroenterology/Renal/Urology)	240-276-0115
21 CFR 884.xxxx	(Obstetrics/Gynecology)	240-276-0115
21 CFR 892.xxxx	(Radiology)	240-276-0120
Other		240-276-0100

Also, please note the regulation entitled, "Misbranding by reference to premarket notification" (21 CFR 807.97). You may obtain other general information on your responsibilities under the Act from the Division of Small Manufacturers, International and Consumer Assistance at its toll-free number (800) 638-2041 or (301) 443-6597 or at its Internet address http://www.fda.gov/cdrh/industry/support/index.html.

Sincerely yours,

Nancy C. Brogdon
Director, Division of Reproductive,
 Abdominal, and Radiological Devices
Office of Device Evaluation
Center for Devices and Radiological Health

Enclosure

Indications for Use

510(k) Number (if known): ~~Not Known~~ *K052640*

Device Name: Gemini Raptor

Indications for Use:

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   o   The evaluation, detection and diagnosis of lesions, disease and organ function such as but not limited to cancer, cardiovascular disease, and neurological disorders.
   o   The detection, localization, and staging of tumors and diagnosing cancer patients.
   o   Treatment planning and interventional radiology procedures.

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Prescription Use ✓
(Part 21 CFR 801 Subpart D)   **AND/OR**   **Over-The-Counter Use** _____
                                                             (21 CFR 801 Subpart C)

(PLEASE DO NOT WRITE BELOW THIS LINE-CONTINUE ON ANOTHER PAGE OF NEEDED)

Concurrence of CDRH, Office of Device Evaluation (ODE)

_____
(Division Sign-Off)
Division of Reproductive, Abdominal,
and Radiological Devices
510(k) Number _____ *K052640*

Page _1_ of _1_

EXHIBIT 10

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Philips showcases clinical results of time-of-flight imaging for PET/CT

Health Imaging News | June 7, 2006 | SNM 360

Philips Medical Systems this week revealed clinical results from its Gemini TF (Time of Flight) PET/CT system and introduced an enhanced JETStream Workspace version 3.0 which offers new workflow and image display enhancements, new image analysis tools, as well as upgrades in clinical applications such as cardiac, bone, renal, salivary and brain.

GEMINI TF features time of flight PET imaging, which Philips calls TruFlight. Regardless of patient size, the system is designed to improve image quality, consistency and performance with low count-rate imaging, according to Philips. It enables small lesion detectability and permits higher patient throughput thanks to a reduction in noise resulting in higher image quality, shorter scans or lower dose. Three units are in field tests – one at the the Hospital of the University of Pennsylvania conducting research on four to five patients daily; one at University Hospitals in Cleveland imaging seven to eight patients a day and focused on clinical work; and one at Montefiore focused on quick image acquisitions that images about 15 patients per day, Philips said. Full commercial release of the system is slated for late this month.

The enhanced version of the JETStream Workspace version 3.0 offers new workflow and image display enhancements and upgraded clinical applications. It also now includes IDL – the programming language for data visualization and analysis developed by RSI – that is now available on the workspace. It allows customers to develop and customize their own applications. All in all, JETStream Workspace is an integrated, personalized workflow management system

designed to help clinicians operate with more speed, diagnose with greater accuracy, convey results to referring physicians faster and more conveniently, and run a practice more effectively.

Version 3.0 will be available as a software-only upgrade.

Philips also is featuring the new PET/CT Viewer application for the Extended Brilliance Workspace, launched in March at the American College of Cardiology meeting, which provides PET users with integrated image review and analysis environment for routine clinical evaluation of PET/CT examinations. It is adaptable to the workflow needs of individual users and substantially improves workflow and efficiency for routine clinical review. It also allows applications to be put on an enterprise network.

The company also is showcasing its Astonish 2.0 image processing tool that began shipping in January. It is installed at more than 250 sites.

EXHIBIT 11

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Philips' highlights enhanced PET/CT, 'green' BrightView SPECT

Health Imaging News | June 6, 2007 | SNM 360

Royal Philips Electronics this week at SNM 2007 in Washington, D.C., announced enhancements to Philips GEMINI TF PET/CT, a time-of-flight PET/CT, and the nuclear medicine debut of a "green" BrightView SPECT, among other technologies.

 "The breadth of our nuclear medicine products and solutions in PET, SPECT, molecular imaging (MI), preclinical imaging and radiation oncology promote clinical confidence for the physician and peace of mind for the patient," said Jay Mazelsky, senior vice president, nuclear medicine, for Philips Medical Systems. "Philips recognizes the importance of accurately viewing the physiological process at a molecular level and works to develop technologies that help our customers detect pathology earlier, faster and more accurately."

Philips emphasized that its installed for the GEMINI TF PET/CT is growing, with more than 30 installed systems worldwide. The GEMINI TF with time-of-flight imaging has demonstrated improved image quality, reduced dose, faster scan times, and consistent image quality across all patient sizes.

Dr. Jim O'Donnell, section chief of Nuclear Imaging at University Hospitals Case Medical Center said of the system, "We've really gone another giant step forward in image resolution with time-of-flight. And the differential improvement in moving from conventional PET to time-of-flight is most prominent in larger patients because it overcomes the inherent physiological problems of size. The system really cleans up the scans in these larger patients."
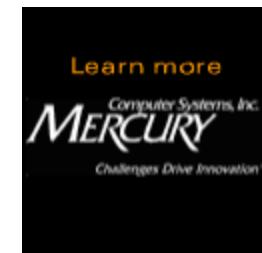
Also on display was the company's compact BrightView SPECT. The system's BodyGuard feature automatically contours to the patient, using a customizable scan distance preset by the operator. Also, Philips' CloseUp technologies enable higher resolution through smart software, new electronics and minimal distance between detector and patient.

Philips also boasted that the BrightView is also its "green flagship" product, thus BrightView with a sustainable life cycle in mind, using less than 50 percent of the hazardous substances found in its predecessor. BrightView is also designed to offer significant advances on packaging, recycling and disposal.

The company also showcased its MOSAIC HP, a part Philips' comprehensive preclinical imaging product portfolio. The system has extra-long imaging bore and long axial field of view, useful for a variety of research subjects as well as the capability to perform bio-distribution studies on a whole subject (mice) in a single bed position. Equipped with a high performance LYSO detector and optional subject handling system compatible with the NanoSPECT/CT system, MOSAIC HP addresses the key requirements of research scientists and is setting new standards in preclinical molecular imaging.

Other highlights at the show included:

- PET/CT Pulmonary Toolkit for Respiratory Correlated Imaging – Respiratory correlated imaging applied to PET improves the accuracy of PET attenuation correction and Standard Uptake Value (SUV) calculations, assists in small lesion detection and facilitates more precise localization;

- PET/CT Viewer for Philips iSite PACS and version 1.5, providing users with an integrated, powerful, yet simple image review and analysis environment for routine clinical evaluation of PET/CT examinations. Philips has extended the availability of the PET/CT Viewer beyond the Philips Extended Brilliance Workspace to the Philips iSite PACS, along with introducing the latest release of version 1.5;

- NetForum PET/CT Community – Previously available to Philips CT and MR customers only, the NetForum PET/CT community is connecting Philips PET/CT customers from around the globe in a moderated virtual users meeting to share clinical experiences, learn from each other and optimize results;

- NanoSPECT/CT – Available through a distribution agreement with Bioscan Inc. announced earlier this year, NanoSPECT/CT will help accelerate preclinical research, the discovery of new targeted biomarkers and the development and validation of new molecular diagnostic and therapeutic applications; and

- Philips announced the commercial release of the JETStream Workspace 3.0, an

integrated, personalized workflow solution for nuclear medicine that includes new process and image display enhancements, new image analysis tools and upgraded clinical applications for cardiac, bone, renal, salivary, lung and brain studies.

EXHIBIT 12

![RT image logo]

the weekly source for radiology professionals

<< **vol. 19, no. 13 - March 27, 2006** >>

Philips Medical Systems
Gemini TF PET/CT system

Article available online at: http://www.rt-image.com/032706TS

Philips Medical Systems, Andover, Mass., announces Gemini TF, a new PET/CT system. The Gemini TF is the first PET system to use atomic particle time-measurements to deliver increased image quality and consistency, thus assisting in earlier disease detection in patients.

Gemini TF is the world's first commercially available time-of-flight PET/CT system, in which gamma rays are more accurately tracked using minute time measurements. Raising effective image sensitivity by more than two times over conventional PET, the Gemini TF delivers benefits for both patients and clinicians. Image acquisition is shortened to less than 10 minutes for a whole-body PET scan, even for larger patients, who had previously needed additional scan time. The Gemini TF also features Philips patented OpenView gantry design, which promotes patient comfort.

In a conventional PET system, a decaying radioactive agent is injected into the patient. As each nucleus decays, it releases a positron, which immediately collides with an electron, releasing two gamma rays that travel away from the collision zone at 180 degrees from each other. It is these pairs of gamma rays that are observed by the PET scanner, which uses this information to calculate where the agent is concentrated, thus creating an image of the affected area. Although the gamma rays in each pair arrive at slightly different times depending on their origination, this is not traditionally measured. With time-of-flight, however, this time difference can be measured, enabling the point of origination to be more accurately predicted and leading to more accurate imaging.

The combined benefits of faster sampling, longer useful imaging times from short-lived isotopes and the use of new low-efficiency tracers are set to increase the utility of PET/CT for every healthcare stakeholder. The technology also opens the pathway to enable the molecular imaging applications of the future.

"This addition to our broad portfolio demonstrates our technology leadership, and our ability to translate that expertise into clinical solutions which integrate seamlessly into the patient care cycle," says Peter Cempellin, general manager of Philips' PET/CT division. "Gemini TF is a step-change for PET, delivering greatly improved performance and with it the possibility of earlier detection of disease and earlier treatment for patients in the future."

— Philips Medical Systems
www.medical.phillips.com
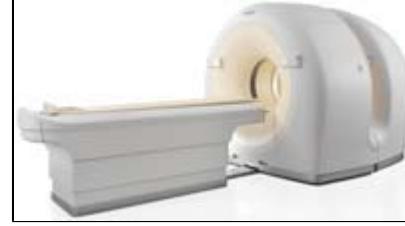
The Gemini TF is the first PET system to use atomic particle time measurements to deliver increased image quality and consistency. (Philips Medical Systems)

EXHIBIT 13

PreLude™ 420

It's what's Inside that Counts!

Scintillation Material

PreLude™ 420 (Lu$_{1.8}$Y$_{.2}$SiO$_5$:Ce) is a Cerium doped lutetium based scintillation crystal that offers high density and a short decay time. It has an improved light output and energy resolution compared to BGO (Bi$_4$Ge$_3$O$_{12}$), which has a similar density. Applications that require higher throughput, better timing and better energy resolution will benefit from using PreLude™ 420 material.

PreLude™ 420 scintillator has shown up to five times the light emission of BGO. The measured energy resolution for 662 keV photons for a 30mm diameter x 15mm long crystal is 7.1% (see the energy spectrum below). A typical value for BGO is 12%.

The emission of scintillation light matches well with the sensitivity spectrum of most PMTs. The quantum efficiency (Q.E.) of a standard bialkali ETI 9266 PMT is 25% at the peak of the emission.

Properties –

Density [g/cm^3]: 7.1

Hygroscopic .... no

Attenuate length for 511keV (cm): 1.2

Wavelength of emission max.[nm] 420

Refractive index@emission max. 1.81

Decay time [ns]: 41

Energy resolution [%]: 8.0

Light output, photons per keV: 32

Average temperature coefficient from 25 to 50° C (%/^{o}C): .... +0.04

Figure 1. PreLude™ 420 Response to 662 keV Photons
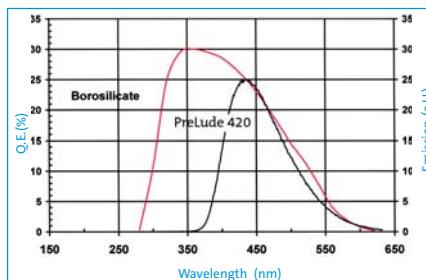
Figure 3. PreLude™ 420 Emission & ETI 9266 Q.E. (Q.E. data courtesy of Electron Tubes, Inc.)

The 1/e decay time of PreLude™ 420 crystal is 41ns, which is much shorter than the decay time of BGO. It is a single exponential with no long components present. This allows for higher rates, greater throughput and better timing.

PET applications have traditionally used arrays of BGO. PreLude™ 420 crystal competes directly on density and surpasses BGO on energy resolution, timing and throughput.

The PreLude™ 420 material is a lutetium-based scintillator which contains a radioactive isotope ^{176}Lu, a naturally occurring beta emitter.


Figure 2. PreLude™ 420 response to 511 keV with R3241 PMT

SAINT-GOBAIN

CRYSTALS

PreLude™ 420
Scintillation Material

Saint-Gobain Crystals has also developed a unique expertise in manufacturing millimeter-sized arrays.
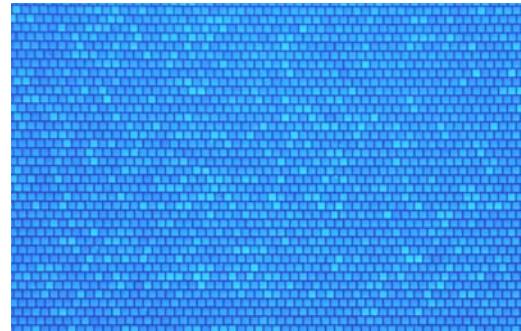
Example of our precision pixel alignment technology
Material: LSO

SAINT-GOBAIN
CRYSTALS

Absorption Efficiency of PreLude™ 420

Percent Absorption vs Energy (keV)

50 mm
40 mm
30 mm
20 mm
10 mm
5 mm
3 mm
2
1
½ mm
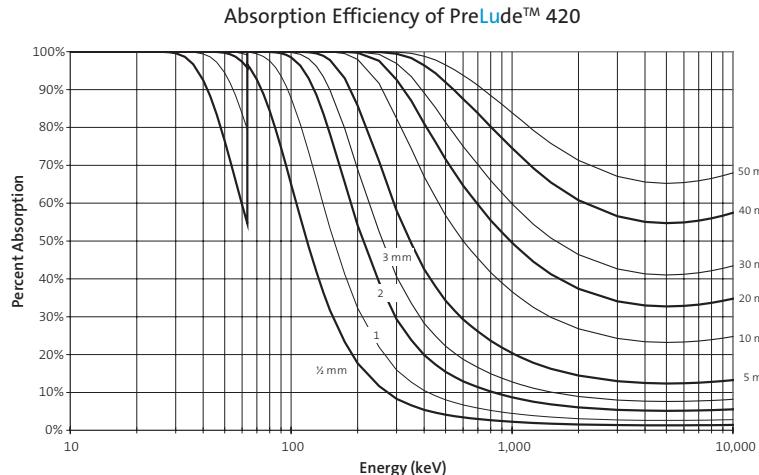
Figure 4. Gamma and X-ray absorption efficiency for various thicknesses of PreLude 420 material. Data compiled by C. M. Rozsa (presented in Saint-Gobain Crystals brochure "Efficiency for Selected Scintillators.")

Property	PreLude™ 420	BGO	LSO
Density [g/cm³]	7.1	7.1	7.4
Attenuation length for 511 keV (cm)	1.2	1.0	1.15
Decay time [ns]	41	300	40
Energy resolution	8.0	12.0	10.0
Light output, photons per keV	32	9	26
Average temperature coefficient from 25 to 50ºC (%/ºC)	+0.04	-1.2	-1.3

Table comparing principal properties of PreLude™ 420 versus BGO and LSO

(6-04)

EXHIBIT 14

SAINT-GOBAIN
CRYSTALS

MATERIAL SAFETY DATA SHEET

Date: March 2007

PRODUCT: LUTETIUM YTTRIUM SILICON DIOXIDE (LYSO) CRYSTAL, CERIUM DOPED

* * * Section 1 - Chemical Product and Company Identification * * *

Chemical Name: Rare Earth Oxide Mixture
Product Use: Inorganic Scintillation Detector Crystal
Manufacturer Information

Saint-Gobain Crystals
12345 Kinsman Road
Newbury, Ohio 44065

Phone: (440)-564-2251
Fax: (440) 564-8047
Emergency # (440)-248-7400
Mfg Contact: Heather Harper, Environmental, Health,
Safety Supervisor

* * * Section 2 - Composition / Information on Ingredients * * *

CAS #	Component	Percent
12032-20-1	Lutetium oxide	81
7631-86-9	Silicon dioxide, amorphous	14
11130-29-3	Yttrium oxide	5

Component Related Regulatory Information
   This product may be regulated, have exposure limits or other information identified as the following: Nuisance
   particulates.
Component Information/Information on Non-Hazardous Components
   Product is a solid material produced by melting individual components together, and cooling to a crystalline solid
   having its own unique properties. Processing of this material may produce dusts that are considered hazardous
   under 29 CFR 1910.1200 (Hazard Communication).

* * * Section 3 - Hazards Identification * * *

Emergency Overview
   This is a non-flammable, non-reactive solid material. It is supplied in the form of an odorless, transparent to light
   yellow solid. Exposure to dust may be irritating to eyes, nose and throat.
Potential Health Effects: Eyes
   Dust or powder may irritate eye tissue.
Potential Health Effects: Skin
   Dust or powder may irritate the skin.
Potential Health Effects: Ingestion
   Ingestion of this product may cause gastrointestinal irritation.
Potential Health Effects: Inhalation
   Dusts of this product may cause irritation of the nose, throat, and respiratory tract.
HMIS Ratings: Health: 1 Fire: 0 Reactivity: 0 Pers. Prot.: E: Safety glasses, gloves, nuisance dust mask
Hazard Scale: 0 = Minimal 1 = Slight 2 = Moderate 3 = Serious 4 = Severe   * = Chronic hazard

* * * Section 4 - First Aid Measures * * *

First Aid: Eyes
   Flush immediately with water for at least 15 minutes. Do not rub eyes. If irritation persists get medical attention.
First Aid: Skin
   For skin contact, wash immediately with soap and water. If irritation persists, get medical attention.
First Aid: Ingestion
   If the material is swallowed, get immediate medical attention or advice – Do not induce vomiting.

First Aid: Inhalation

Remove affected person immediately to fresh air. If respiratory irritation occurs, if breathing becomes difficult, or if other symptoms develop, seek medical attention immediately.

First Aid: Notes to Physician

Product is a mixture of insoluble rare earth (Lutetium and Yttrium) oxides. While unlikely to occur due to insoluble nature of material, the symptoms of acute rare earth toxicity include spontaneous defecation, writhing, ataxia, labored respiration, sedation, hypotension, and cardiovascular failure.

* * * Section 5 - Fire Fighting Measures * * *

Flash Point: Not available

Upper Flammable Limit (UFL): Not available

Auto Ignition: Not available

Rate of Burning: Not available

Method Used: Not available

Lower Flammable Limit (LFL): Not available

Flammability Classification: Non-flammable

General Fire Hazards

This material will not burn.

Hazardous Combustion Products

None expected.

Extinguishing Media

Use methods for the surrounding fire.

Fire Fighting Equipment/Instructions

Wear full protective clothing, including helmet, self-contained positive pressure or pressure demand breathing apparatus, protective clothing and face mask.

NFPA Ratings: Health: 1 **Fire:** 0 **Reactivity:** 0

Hazard Scale: 0 = Minimal 1 = Slight 2 = Moderate 3 = Serious 4 = Severe

* * * Section 6 - Accidental Release Measures * * *

Containment Procedures

Minimize generation of dusts.

Clean-Up Procedures

Treat as nuisance dust. Wear respiratory protection during cleanup. Sweep up or vacuum material and place in appropriate container for disposal. Rinse spill area with water.

Evacuation Procedures

Ordinarily not necessary. If large quantity of dust is released, isolate area and keep unnecessary personnel away.

Special Procedures

Avoid inhalation of dust from the spilled material. Follow all Local, State, Federal and Provincial regulations for disposal.

* * * Section 7 - Handling and Storage * * *

Handling Procedures

Follow good industrial hygiene practices when handling this material. Keep formation of airborne dusts to a minimum.

Storage Procedures

Store in a cool, dry area away from moisture and excessive heat.

* * * Section 8 - Exposure Controls / Personal Protection * * *

Exposure Guidelines

A: General Product Information

Keep formation of airborne dusts to a minimum.

B: Component Exposure Limits

Lutetium oxide   (12032-20-1)

ACGIH: 10 mg/m3 TWA (inhalable fraction, particulate matter containing no asbestos and <1% crystalline silica); 3 mg/m3 TWA (respirable fraction, particulate matter containing no asbestos and <1% crystalline silica) (related to Particulates not otherwise specified (PNOS))

OSHA: 15 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction) (related to Particulates not otherwise regulated)

Silicon dioxide, amorphous   (7631-86-9)

NIOSH: 6 mg/m3 TWA

Engineering Controls
>   Ensure adequate ventilation to remove and prevent buildup of dust generated during handling or processing.

PERSONAL PROTECTIVE EQUIPMENT

Personal Protective Equipment: Eyes/Face
>   Wear safety glasses.

Personal Protective Equipment: Skin
>   Normal work clothing (long sleeved shirts and long pants) is recommended. Use impervious gloves.   Wash hands thoroughly after handling.

Personal Protective Equipment: Respiratory
>   Treat as nuisance dust. Wear NIOSH/MSHA approved respirator when workplace conditions warrant use.

Personal Protective Equipment: General
>   Use good industrial hygiene practices in handling this material.

* * * Section 9 - Physical & Chemical Properties * * *

Appearance:	Transparent to light yellow	**Odor:**	Odorless
Physical State:	Solid	**pH:**	NA
Vapor Pressure:	None	**Vapor Density:**	NA
Boiling Point:	NA	**Melting Point:**	>2000°C (3632°F)
Solubility (H2O):	Insoluble	**Specific Gravity:**	7.21

* * * Section 10 - Chemical Stability & Reactivity Information * * *

Chemical Stability
>   Stable under normal conditions.

Chemical Stability: Conditions to Avoid
>   Avoid dispersion of dust in air.

Incompatibility
>   Very slightly soluble, even in strong acids.

Hazardous Decomposition
>   None known or expected.

Hazardous Polymerization
>   Will not occur.

* * * Section 11 - Toxicological Information * * *

Acute and Chronic Toxicity

A: General Product Information
>   Dust generated from grinding or polishing material is comparable to a nuisance dust. Excessive airborne concentrations of nuisance dusts may cause irritation to eyes, skin, or mucous membranes by chemical or mechanical action. Asthma and chronic respiratory conditions may be aggravated by exposure to product dust.
>
>   Product is a mixture of insoluble rare earth (Lutetium and Yttrium) oxides. While unlikely to occur due to insoluble nature of material, the symptoms of acute rare earth toxicity include spontaneous defecation, writhing, ataxia, labored respiration, sedation, hypotension, and cardiovascular failure.

B: Component Analysis - LD50/LC50
>   **Yttrium oxide (11130-29-3)**
>   Oral LD50 Rat: 5 gm/kg

Carcinogenicity

A: General Product Information
>   None identified.

B: Component Carcinogenicity
>   **Silicon dioxide, amorphous (7631-86-9)**
>   IARC: Monograph 68, 1997 (Group 3 (not classifiable))

Epidemiology
>   No information available.

Neurotoxicity
>   No information available.

Mutagenicity
>   No information available.

Teratogenicity
>   No information available.

* * * Section 12 - Ecological Information * * *

Ecotoxicity
A: General Product Information
> No information available for the product.

B: Component Analysis - Ecotoxicity - Aquatic Toxicity
> No ecotoxicity data are available for this product's components.

Environmental Fate
> No information available for the product.

* * * Section 13 - Disposal Considerations * * *

US EPA Waste Number & Descriptions
A: General Product Information
> Wastes must be tested using methods described in 40 CFR Part 261 to determine if it meets applicable definitions of hazardous wastes.

B: Component Waste Numbers
> No EPA Waste Numbers are applicable for this product's components.

Disposal Instructions
> Waste must be handled in accordance with all federal, state, provincial, and local regulations.

* * * Section 14 - Transportation Information * * *

US DOT Information
> **Shipping Name:** Not regulated as dangerous goods.
> **Additional Info.:** None.

International Transportation Regulations
> No additional information available.

* * * Section 15 - Regulatory Information * * *

US Federal Regulations
A: General Product Information
> None identified.

B: Component Analysis
> None of this products components are listed under SARA Section 302 (40 CFR 355 Appendix A), SARA Section 313 (40 CFR 372.65), or CERCLA (40 CFR 302.4).

State Regulations
A: General Product Information
> Other state regulations may apply. Check individual state requirements.

B: Component Analysis - State
> The following components appear on one or more of the following state hazardous substances lists:

Component	CAS	CA	MA	MN	NJ	PA	RI
Lutetium oxide ([1]related to Nuisance particulates)	12032-20-1	No	No	No	No	No	Yes [1]
Silicon dioxide, amorphous	7631-86-9	Yes	Yes	Yes	Yes	Yes	No

Other Regulations
A: General Product Information
None identified.

B: Component Analysis - Inventory

Component	CAS #	TSCA	DSL	EINECS
Lutetium oxide	12032-20-1	Yes	Yes	Yes
Silicon dioxide, amorphous	7631-86-9	Yes	Yes	Yes
Yttrium oxide	11130-29-3	Yes	No	Yes

C: Component Analysis - WHMIS IDL
> The following components are identified under the Canadian Hazardous Products Act Ingredient Disclosure List:

Component	CAS #	Minimum Concentration
Silicon dioxide, amorphous	7631-86-9	1%; English Item 1403; French Item 1488

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* * * Section 16 - Other Information * * *

Other Information

Reasonable care has been taken in the preparation of this information, but the manufacturer makes no warranty of merchantability or any other warranty, expressed or implied, with respect to this information. The manufacturer makes no representations and assumes no liability for any direct, incidental or consequential damages resulting from its use.

Key/Legend

ACGIH = American Conference of Governmental Industrial Hygienists. AICS = Australian Inventory of Chemical Substances. CAS = Chemical Abstract Service. CERCLA = Comprehensive Environmental Response, Compensation and Liability Act. CFR = Code of Federal Regulations. CHEMTREC = Chemical Transportation Emergency Center. DSL = Canadian Domestic Substance List. EINECS = European Inventory of New and Existing Chemical Substances. EPA = Environmental Protection Agency. HEPA = High Efficiency Particulate Air. HMIS = Hazardous Materials Identification System. IARC = International Agency for Research on Cancer. IDLH = Immediately Dangerous to Life and Health. NDSL = Canadian Non-Domestic Substance List. NFPA = National Fire Protection Association. NIOSH = National Institute of Occupational Safety and Health. NJTSR = New Jersey Trade Secret Registry. NTP = National Toxicology Program. OSHA = Occupational Safety and Health Administration. NA = Not available or Not Applicable. SARA = Superfund Amendments and Reauthorization Act. STEL = Short Term Exposure Limit. TDG = Transportation of Dangerous Goods. TLV = Threshold Limit Value. TSCA = Toxic Substances Control Act. WHMIS = Workplace Hazardous Materials Information System.

Contact: Heather Harper, Environmental, Health, Safety Supervisor
Contact Phone: (440) 564-2251

# EXHIBIT 15

Awards

SOCIETY AWARDS

MERIT AWARD
Charles L. Melcher

The 2006 NPSS Merit Award was given to Chuck Melcher. Following a background in luminescence physics and materials science as a graduate student at Washington University and as a post-doc at Caltech, Chuck began to focus on scintillation materials while at Schlumberger-Doll Research. As Program Leader of Advanced Detectors, he led a group that conducted fundamental investigations of various scintillation materials for potential use as gamma-ray detectors in geophysical exploration. These investigations led to the development of compact gamma-ray detectors for down-hole water saturation measurements in producing oil wells, a technique that continues to be a commercial standard in the industry. While at Schlumberger, Chuck invented a new scintillator material known as LSO (cerium-doped lutetium oxyorthosilicate, Lu_2SiO_5:Ce) which has outstanding properties for gamma ray detection. Its combination of high density and atomic number, high light output, and short decay time gave it significant advantages over previously known scintillators. LSO was quickly recognized as having particularly valuable properties for use in Positron Emission Tomography (PET), a molecular imaging technique for the early detection of diseases such as cancer and Alzheimer's. His first presentation about LSO earned an award at the NSS-MIC conference in Santa Fe, and the corresponding paper is one the most cited scintillator articles in the Transactions on Nuclear Science.

In 1996 Chuck moved to CTI, Inc. to form a team that would continue to develop LSO for commercial PET applications. This team collaborated with numerous researchers world wide to further investigate fundamental properties of LSO while also developing prototype growth systems to demonstrate large scale production feasibility. The successful development of a commercial scale growth process enabled the team to design and construct of one of the largest crystal manufacturing factories in the world whose output now provides LSO crystals for hundreds of Positron Emission Tomography systems annually. The factory also produces large crystals for potential use in particle physics experiments.

When CTI merged with Siemens Medical Solutions in 2005, Chuck organized a partnership between the University of Tennessee and Siemens to form the Scintillation Materials Research Center (SMRC). He joined the faculty of the Materials Science and Engineering Department at the University of Tennessee and became Director of the Center. The SMRC is a groundbreaking example of a cooperative partnership between industry and academia, providing unique research opportunities for engineering students and an integrated approach for the commercial realization of innovations in scintillation materials.

LSO has become the standard against which new scintillator materials are often compared. During the 15 years since its introduction, no scintillator has yet equaled its combination of high light yield, fast decay time, high density and atomic number, and environmental stability. Chuck not only discovered and patented LSO and carried out much of the initial basic research on its properties, but he also led its development to the industrial production level and its widespread implementation in positron emission tomography (PET). It is arguably the most commercially successful scintillator of the last 20 years, now used in nearly half of the clinical PET scanners currently manufactured as well as in the vast majority of small animal PET scanners. The discovery and commercialization of LSO is often
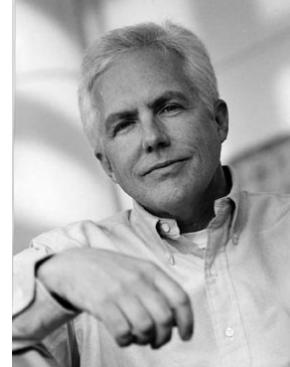
Charles L. Melcher
Merit Award

mentioned as one of the major developments in nuclear medical imaging of the last few decades. In addition, it is now under consideration for the next generation of high energy physics calorimeters.

Chuck has been an active member of the IEEE and the NPSS for many years. In addition to numerous program committees, he has served on the Radiation Instrumentation Steering Committee and the Constitution and Bylaws Committee. He currently serves as Vice Chair and Chair-elect of the Radiation Instrumentation Technical Committee. In addition, he serves as Associate Editor of the Transactions on Nuclear Science.

Citation: For outstanding contributions to the field of scintillation materials, particularly for the invention, development, and commercialization of LSO scintillators and the resulting impact on positron emission tomography and nuclear medicine.

Chuck Melcher can be reached at Scintillation Materials Research Center, University of Tennessee,Knoxville, TN 37996-2000; Phone: +1 865 974-0254: Fax: +1 865 974-4998: E-mail: cmelcher@utk.edu.

RICHARD F. SHEA DISTINGUISHED MEMBER AWARD
Paul V. Dressendorfer

Paul V. Dressendorfer received the B.S. degree in Physics from the California Institute of Technology in 1972, and the M.S., M.Phil., and Ph.D. degrees in Solid State Physics from Yale University in 1973, 1974, and 1978, respectively. He recently retired from Sandia National Laboratories as the manager of the Biomolecular Interfaces and Systems Department at Sandia National Laboratories. This group focused on the science of integration of biomolecular processes, biological principles, biomimetic materials, and biomolecular function into nano- and microscale systems. His earlier research activities and publications have covered a wide range of areas including semiconductor device physics, basic radiation damage mechanisms, characterization of radiation effects, hardened technology development, hardness assurance, optoelectronic devices, multichip modules, advanced electronic and microsystem packaging, thermal management, frequency devices, sensors and transducers, and microsystem electronics. He has been active in a variety of IEEE activities, including positions such as general chair of the Nuclear and Space Radiation Effects Conference (NSREC) and of the Semiconductor Interface Specialists Conference (SISC), short course instructor and chair of the NSREC, technical program chair of the SISC, IEEE Section Membership chair, IEEE Standards Committee member, and member of the NPSS AdCom, Radiation Effects Steering Group, and Radiation Instrumentation Steering Committee. He is a Fellow of the IEEE and a recipient of the IEEE Third Millennium Award. He has been the Editor-in-Chief of the IEEE Transactions on Nuclear Science since 1993, is currently the Editor-in-Chief (Chair of the Publications Committee) of the NPSS, and is the NPSS Liaison to the TAB Transactions Committee. He recently reorganized the Editorial Board and review processes for the Transactions on Nuclear Science; a similar structure is also being implemented in the Transactions on Plasma Science.

Paul V. Dressendorfer
Richard F. Shea Distinguished Member Award

Citation: In appreciation of 14 years as editor for NPSS. Special recognition as Editor-in–Chief for reorganizing and implementing an effective operating structure for the Transactions on Nuclear Science.

Paul Dressendorfer can be reached at p.dressendorfer@ieee.org.

EARLY ACHIEVEMENT AWARD

JOHN W. LUGINSLAND

John Luginsland received the B.S.E, M.S.E, and Ph.D. degrees from Department of Nuclear Engineering at the
University of Michigan in Ann Arbor, Michigan. His doctoral research involved the theoretical and computational analysis of two-beam accelerators, field emission physics, and coherent microwave generation. In 1996, he joined the Air Force Research Laboratory at Kirtland AFB, NM – first as a National Research Council Resident Postdoctoral Research Associate, and later as a staff member in the Center for Plasma Theory and Computation. In 2001, he moved to Science Applications International Corporation as a senior scientist and program manager. In 2003, he joined NumerEx of Albuquerque, NM, at a satellite office in Ithaca, NY.

At AFRL, Dr. Luginsland performed research advancing the state-of-the-art in both high power microwave (HPM) sources and high performance computational models of electromagnetic devices. He led a team in basic research of multi-dimensional space-charge limited flows that led to mitigation of pulse shortening in the magnetically insulated line oscillator. He also participated in the development of ICEPIC, a massively parallel electromagnetic particle-in-cell code, with application to HPM sources. He and his colleagues were honored with the Air Force's Advanced Technology Development Award during this time.

At SAIC, Dr. Luginsland developed parametric design tools for advanced armor and survivability systems, which remain in use today. He was a program manager and test planner in integrating these systems into next generation platforms.

At NumerEx, Dr. Luginsland has applied computational plasma physics to closely support experimental technology development at various phases of maturity, in compact HPM sources, emission physics and cathode designs, MHD effects in high power fuses for survivability systems, electrically enhanced combustion, and quantum vacuum nanoelectronics. His wider interests include the coupling of parametric and first-principles physics software, high-performance computing and optimization algorithms, and application of virtual prototyping to speed development and deployment of electromagnetic high technology systems.

The award will be presented at the Pulsed Power Plasma Science conference in Albuquerque, NM in June 2006.

Citation: For contributions to the development and application of theoretical and computational methods leading to enhanced understanding and improved experimental performance of high current diodes and high power microwave sources.

John W. Luginsland has been a member of the IEEE and NPSS since 1994, and can be reached at NumerEx, 401 E. State St., Suite 304, Ithaca, NY 14850; Phone: +1 607 277-4272; Fax: +1 607 697-0212; E-mail: John.Luginsland@NumerEx.com

John W. Luginsland
Early Achievement Award

GRADUATE STUDENT ACHIEVEMENT AWARDS
Xin Dai

Xin Dai was born in Hubei China in 1976. He received his B.E. degree in 1996 and M.S. degree in 1999, both in Electrical Engineering from Huazhong University of Science and technology, Wuhan, China, and the Ph.D. degree from the University of Tennessee, Knoxville, TN, in 2006. He is currently a Postdoctoral affiliate at Plasma Science Laboratory at the University of Tennessee at Knoxville. His research interests include industrial plasma research and application, especially at atmospheric pressure, pulsed power and high power electronics.
Dr. Xin Dai is a member of IEEE, AIAA and APS.

Carrie B. Hruska

Carrie Hruska has been named a recipient of the IEEE NPSS Graduate Scholarship Award given to recognize contributions to the fields of Nuclear and Plasma Sciences. Hruska is a graduate student at Mayo Clinic College of Medicine in Rochester, MN and will graduate with a Ph.D. in Biomedical Engineering in May 2007. She received her undergraduate degree in electrical engineering from South Dakota State University in 2002.

Hruska's doctoral thesis research is focused on the use of small pixilated detectors for a nuclear medicine technique to image breast cancer, called Molecular Breast Imaging (MBI). She is currently working with a prototype CZT detector, and the goal of her work is to advance MBI by examining the patient-related factors that limit tumor detection, optimizing the technical parameters of the imaging system, and developing a method to localize tumors in the breast. The central hypothesis is that recent advances in small detector technology combined with new radiopharmaceuticals will permit the development of an MBI system that will provide reliable detection and localization of small breast tumors (< 10 mm). MBI is currently under evaluation at Mayo as a screening technique for women with dense breast tissue who are at increased risk for breast cancer.

Xin Dai

Carrie Hruska

Randolph McKinley

Randolph McKinley recently received his Ph.D. in Biomedical Engineering from Duke University in Sept. 2006. He currently works in the Multi-Modality Imaging Lab (MMIL) at Duke concentrating on X-ray computed mammotomography, a dedicated 3D breast imaging technique, which includes a practicable quasi-monochromatic cone beam X-ray source that can move about an object 3-dimensionally collecting transmission data. In addition, he holds a Master of Science in Electrical Engineering from Columbia University and Bachelor of Science degrees in both Biology and Electrical Engineering from University of New Brunswick.

Randolph McKinley

Xing Zhou

Xing Zhou is in the process of completing her PhD research in the interdisciplinary graduate program in materials science at Vanderbilt University. She has made significant contributions to the understanding of the separate and combined effects of bias-temperature stress and ionizing radiation exposure for MOS devices with high-K dielectric materials. Xing has authored 11 publications, and was first author on four of them. A paper on which Xing was first author, "Bias-temperature instabilities and radiation effects in MOS devices," was one of 11 papers nominated for the Outstanding Conference Paper Award at the 2005 IEEE Nuclear and Space Radiation Effects Conference (IEEE NSREC) in Seattle, WA. She also received a Paul Phelps Continuing Education Grant for the 2006 IEEE NSREC in Ponte Vedra Beach, FL.

Xing Zhou can be reached by e-mail at: xing.zhou@vanderbilt.edu

Xing Zhou

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